Homework set #4 (assigned 31 March, due 9 April)

Instructions. As always, these homework questions have many parts to them. Make sure you read the entire question and answer each and every part! You do not get any credit for problems or parts of problems that you do not attempt. You should make sure that in all cases your units agree. That is, if you are using meters, seconds, and grams for your calculations, make sure you don't accidentally have any kilometers, years, or kilograms (or, heaven forbid, pounds) in your calculations or solutions. For these reasons and oh-so-many-others, please proofread your homeworks before you turn them in.

1) The nearest star to the Earth is Proxima Centauri, about 4.2 light years distant (4.2 light years = 4×10^{13} km = 1.3 parsecs). A typical very nearby star might be 20 parsecs distant. Escape velocity for our Solar System – that is, the velocity that a comet/asteroid/spaceship must have in order to leave our Solar System – is something like 600 km/sec. What is the travel time, assuming escape velocity, between a typical very nearby star and the Earth? Your answer should be in years.

Life is thought to have originated very early on Earth, probably as early as 3.8 billion years ago (recall that the age of the Earth is around 4.5 billion years). The particularly violent period of the Earth's history called Late Heavy Bombardment ended around 3.9 billion years ago. One criticism/concern about the origin of life on Earth is that perhaps that 100 million years wouldn't be enough time for life to originate here on Earth. The counter-proposal is that life could have originated elsewhere in the Universe and traveled to Earth.

Using the travel time you calculated above, does this proposed solution help at all?

The galaxy is around 100 kiloparsecs across (1 kiloparsec = 1000 parsecs). Assuming life originated around a Sun-like star, from how far across the galaxy could a panspermic life-form travel to the Earth if the oldest Sun-like star in the galaxy is around 10 billion years old? How much time could you allow for life to originate if it originated at the birth of a 10 billion year old star on the opposite side of the galaxy?

The typical density of very nearby Sun-like stars might be around 0.01 Sun-like stars per cubic parsec (think of a volume in space; the volume of a sphere is equal to $\frac{4}{3}\pi r^3$ where r is the radius of the sphere). How many Sun-like stars are there within the typical very nearby volume (of, say, radius 20 pc)? How about in the whole galaxy (assuming that the space density of Sun-like stars is constant throughout, which it almost certainly isn't)? You can assume the galaxy is a sphere (which, again, it isn't). If life had to originate around one of these Sun-like stars in order to travel panspermically to the early Earth, how many eligible Sun-like stars are there from which life could have begun its travels?

Now imagine that you are riding along on a panspermically-rich comet or asteroid that has made its way from another planetary system to our Solar System. You start to approach our Solar System (radius around 50 AU, where 1 AU is 1 Astronomical Unit, which is equal to 1.5×10^8 km); imagine that you have a "top-down" view, where you are looking down on the planets orbiting around the Sun. What is the probability that out of the entire Solar System's area (as seen from your perspective), you will land on Earth? (The planetary radius of Earth is around 6700 km.) It will certainly help you to figure out this problem if you *draw a picture.*

Lastly, how likely do you think this all is? By all, I mean all of the steps you have considered above here. You can calculate this numerically but you do not have to – you can answer in words/thoughts/gut feelings instead.

2) Io is the most volcanically active body in the Solar System. It also has the highest heat flow from its surface. Its heat flow is approximately 2.5 W/m^2; for comparison, the Earth's heat flow is around 0.05 W/m^2 (globally averaged). A Watt (W) is the metric unit of energy flux (energy per second), and a Joule (J) is the metric unit of energy: 1 W = 1 Joule per second. What is the total heat energy escaping from Io, per second? Your answer should be either in J/s or in W.

What is the volume of Io's "crust"? You can assume the "crust" has a thickness of 10 km. If the density of this material is around 3000 kg/m^3, what is the mass of Io's crust?

The *latent heat of melting* is the amount of energy needed to convert a solid substance at its melting temperature to a liquid at the same temperature. For typical volcanic rocks, the latent heat of melting is around 5×10^5 J/kg, which means it takes 5×10^5 J to turn 1 kg of volcanic rock from solid at its melting temperature to liquid at the same temperature. Assuming that providing the latent heat of melting is the only important time-limiting step in turning Io's rocks to liquid, how much time does it take to completely melt all of Io's crust? This is the resurfacing time for Io. How many craters would you expect to see on Io? How many have you seen on Io (we have seen at least a couple pictures of Io so far in this class, or you can easily find pictures of Io on the web). What do you think about all this – does it make sense and hold together?

Io gets most of its heat flow from tidal pulling and pushing as it orbits Jupiter. Europa also orbits Jupiter and gets quite a bit of tidal pulling. The heat flow on Europa is around 100 times less than that on Io. The latent heat of melting from solid ice to liquid water is 3.4×10^5 J/kg. If, as some people have proposed, the uppermost 100 km of Europa is a thick water ice layer, what is the timescale to melt this layer? Do you expect Europa to have no, few, some, or many craters on its surface, and why? This surface/interior ocean, some people think, is the reservoir of water that life on Europa could survive in – but only if there is enough liquid water that persists for long enough. (Note: The density of ice is around 1000 kg/m^3.)

You might want to know how to calculate the volume of a spherical shell. The volume of a spherical shell is given by $4\pi r^2 \Delta r$ where r is the radius of the sphere and Δr is the thickness of the shell. This equation is only valid when Δr is much, much smaller than r.

3) Atmospheric pressure is simply the weight (remember Newton's Laws) of the atmosphere pushing down divided by the area upon which the atmosphere is pushing. The metric units of pressure are Newtons/m^2 (also called a Pascal; you might also have heard of pounds per square inch [PSI], which is the English units equivalent).

The surface (atmospheric) pressure on Venus is around 90 bars (surface pressure on the Earth is 1 bar, by definition). Venus' atmosphere is 96% CO_2, compared to 0.035% in the Earth's atmosphere. How much CO_2 is in the Earth's atmosphere? To simplify this calculation, you can assume that the Earth's atmosphere is uniformly dense and has a height of 10 km (this is the Earth's atmospheric *scale height*.). The density of air is around 1 kg/m^3. How much CO_2 is in Venus' atmosphere? The total amount of carbon in/on the Earth is roughly 10^{20} kg; what percent is in the atmosphere? If Venus has the same total carbon inventory, what percent of Venus' total carbon is in the atmosphere? What can you say about Venus' rocks?

Something to keep in mind: not all of the mass of a CO_2 molecule is carbon.

4) In class I've presented you a lot of evidence about the likely past presence of liquid water on Mars. Given all this evidence, and our reasons for knowing that liquid water cannot currently exist on Mars, when do you think that liquid water last flowed on Mars? Why?