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Midterm exam

Astronomy 183
Life in the Universe
Spring, 2010

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Note: The solutions here are abbreviated, just enough to get you going in the right direction. You probably should have written more in your answers than I wrote here.

(1) [15 pts] Define and briefly (just a phrase or two!) give the significance of the following:

racemic
50/50; amino acids; life is not racemic

Late Heavy Bombardment
3.8 Gyr; life arose right after; lots of impacts

carbonaceous chondrite
meteorite with carbon; often containts amino acids; panspermia?

rooting the tree
finding our last common ancestor; understand evolution of life; thermophile

Miller-Urey
experiment that produced amino acids in a lab; 1950s; life can arise naturally

(2) [5 pts] Put the following things in order of size: the wavelength of infrared light; the Sun; the wavelength of ultraviolet light; the Earth; the wavelength of visible light; a proton; microwaves; and you.

smallest
proton
UV
visible
IR
microwaves
me
earth
sun
largest

(3) [5 pts] What is the major significant difference between RNA and DNA? In what way is this difference important in the discussion of the origin and evolution of life?

RNA has one strand, DNA has two strands. DNA's information is better protected by the second backbone. this is data security. RNA is more flexible (catalyst and storage) and must have arisen first, but the information is less secure, more susceptible to mutation.

(4) [10 pts] In what contexts so far in the course has phosphorus (P) been important?

There's something funny about phosphorus and astrobiology. What is the puzzling thing in astrobiology about phosphorus? [There's only one thing we've talked about in this course that is relevant here.]

P appears in ATP/ADP; in nucleic acid bases; and in phospholipids. what's funny is that these three biomolecules all seem to be critical for life on Earth, but P is relatively rare (in terms of cosmic abundance) – so how did life come to use P so critically?

(5) [10 pts] Why is carbon the fundamental building block for life on Earth?

four bonding sites; covalent or ionic; high cosmic abundance; electronegative (so strong bonds); makes chains easily; flexible chemistry (i.e., carbon cycle). NOTE: be careful about circular arguments here. don't tell me "carbon is the most common element in the biosphere" – that is circular.

(6) [10 pts] The synthesis of pre-biotic molecules may have required hot (but not too hot) and also dry and also wet conditions. Explain why these conditions may have been required. What physical environment(s) on the early Earth could have corresponded to this situation? Discuss briefly.

hot: makes reactions go faster. not too hot: or else molecules fall apart. dry: dehydration reactions. wet: do chemistry. physical environment: deep sea vents or hot springs or land-sea interfaces. NOTE: pre-biotic means *before* life.

(7) [10 pts] Draw a plot of cosmic abundances (abundance vs. atomic number) for the Universe at 100 million years after the Big Bang. Draw (on the same plot, or a different one) the cosmic abundances today. Draw (on the same plot, or a different one) the cosmic abundances 15 billion years from now (so the age of the Universe will be roughly 30 billion years). Make sure you label your three different plots so I know which is which. Briefly discuss why your plots look similar and/or different. How is this relevant to astrobiology?

The three plots all look similar in that hydrogen dominates the composition of the Universe (that is, the cosmic abundances) at all times. Second to hydrogen is always helium. However, at 100 million years after the Big Bang, there are essentially no atoms of any other kind in existence in the Universe. This is because all atoms heavier than helium were and are created in stars, and the first star in the Universe did not exist until about 150 or 200 million years after the Big Bang. So the plot of cosmic abundances for 100 million years after the Big Bang shows basically only hydrogen and helium.

The plot of cosmic abundances today you have seen many times. In fact, what I have shown you in this course is the plot of cosmic abundances from the formation of the Solar System, but not much has changed in 4.5 billion years – that's a fine approximation of the cosmic abundances today. In summary, there are now many elements heavier than helium, though none that have abundances anywhere near as high as hydrogen or helium. The cosmic abundance in the Universe 15 billion years from now should be a continuation of this trend: there will be relatively more of everything heavier than hydrogen and helium as elements are created in stars or in supernovae.

Another subtlety is that after very long times (like 30 billion years or), there should be relatively slightly *fewer* radioactive heavy elements and slightly *more* daughter elements. This is because many of the heaviest elements are radioactive, with long half-lives; for example, uranium (atomic number 92) ultimately decays to lead (atomic number 82). The half-lives of ^{235}U and ^{238}U – two isotopes of uranium – are 7×10^8 years and 4.5×10^9 years. When our Solar System formed, only a few half-lives of these isotopes would have passed, so little uranium in the Universe would have decayed all the way to lead, and the uranium abundance would be based on its creation rate. However, after a number more half-lives (15 billion years), most of those uranium atoms would have decayed to lead (remember that after six half-lives, 98% of the original material has decayed.). Even though uranium would still be created in supernova explosions at 30 billion years, the relative enhancement of U is less than that of other elements. Thus, the plot of cosmic abundances showing 15 billion years from now should increase less for uranium and increase slightly more for lead. I tried to show this in the plot I made.

One implication for astrobiology is that perhaps life is more likely at later and later ages of the Universe because the relative abundances of heavy elements (like carbon, oxygen), which we think are crucial for life, increase with increasing age of the Universe. Intersting idea! (Similarly, life would appear to be pretty unlikely at 100 million years after the Big Bang.) Some people said that the abundance of CHON will be

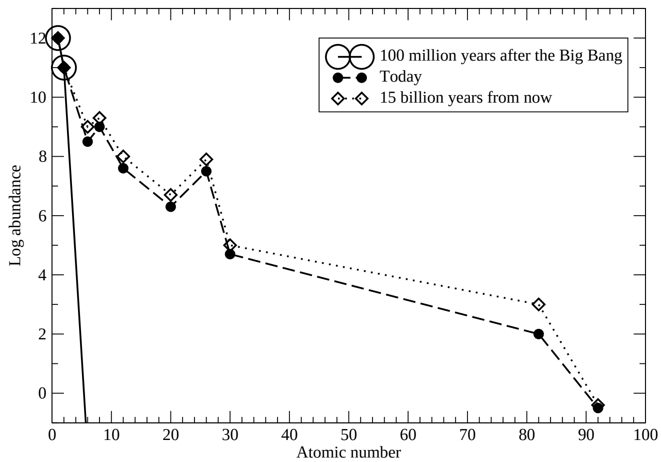

Figure 1: Cosmic abundances as a function of atomic number. The cosmic abundances shown are logarithmic and relative to hydrogen, which is defined as having an abundance of 12 (this is just a convention; it doesn't matter why). I show the abundances for 100 million years after the Big Bang as a solid line with big open circles; today's abundances as small, filled circles with a dashed line; and the abundances 15 billion years from now as open diamonds with a dotted line.

less in 15 billion years because there will be less H. This is true, but only slightly: the Universe will still be mostly H in 15 billion years. The limiting factors for CHON will still be CON. So, overall, in 15 billion years, there will be more CHON than there is today. This might suggest that the probability of life in the Universe increases with the age of the Universe.

Note: There is still some amount of confusion about the timeline and terms of various formation events in the history of the Universe and Solar System. You may need to remind yourself of the difference between the Big Bang and the formation of the Solar System. Also note that the cosmic abundance does not refer to the abundance of elements on the Earth, but in the cosmos – the local galaxy, or even the whole Universe. Also, many people did not answer the question of how is this relevant to astrobiology. Lastly, the Sun's lifetime has nothing to do with this question – we are talking about the whole Universe here.

(8) [10 pts] Which of the anthropic principle or the principle of mediocrity best supports the theory of panspermia, and why?

define one (or both) of these theories. define panspermia, perhaps. then argue why one of these theories better supports panspermia. your mileage may vary.