Extraterrestrial Life: Problem Set #3

Due, in class, Thursday February 28th

1) Outline the key properties that seem to be common to all life on Earth. Explain why the existence of these shared features supports the idea that all life on Earth arose from a common ancestor.

   (lecture #9) Properties common to all life on Earth include the fact that life is contained within cells, relies on proteins made out of amino acids, utilizes DNA as the carrier of hereditary information, and makes use of ATP as an energy carrier. The fact that all life shares these features – in particular the "non-obvious" ones such as the fact that the **same** fairly small set of amino acids is used by almost all life forms – seems very unlikely to be a chance occurrence (i.e. it seems improbable that if life started independently in two different places, *everything* on this list would be the same). Rather it seems likely that all life today was descended from a common ancestor which already possessed these features.

2) Suppose that life is discovered on Mars. Explain how we might be able to determine whether it shares a common ancestor with life on Earth. How would the prospects for making such a determination be affected if all that is found on Mars are fossils of life that died out hundreds of millions of years ago?

   This is basically the same as the previous question. If we discover extant life on Mars and find that it, too, uses the same set of amino acids, is based around DNA and ATP, etc, then plausibly Martian life and Earth life also share a common ancestor (recall this is possible since meteorites ejected from either planet do occasionally wind up on the other). It is unlikely or impossible that we could make this determination if all we find is fossils, since the chemical signatures of DNA etc are rather fragile and would not be likely to survive.

3) Suppose that (hypothetically, since I can't think how this could ever happen) **all** life on Earth were suddenly to die out. Describe how the atmosphere on the now-lifeless Earth would change. For how long would evidence of past human civilization persist (i.e. if an alien civilization were to visit the Earth thousands, millions, or hundreds of millions of years later, how easily could they determine that an intelligent species had once existed there?).

   More or less any reasonable answer was OK for this one, which is very speculative. My own guess is that some traces of civilization (note, note just life, which can be detected even billions of years in the past) would survive for at least 10s of millions of years, although obviously buildings etc would be much shorter-lived (the pyramids are still standing, but showing their age after a few thousand years). Satellites, and probes sent to the moon, might still be there even billions of years in the future.

4) Describe what is meant by extremophiles. Why are extremophiles considered to be important in guiding the search for extraterrestrial life.

(lecture #11) Extremophiles are organisms (archaea and bacteria) that are adapted to live in extreme environments that seem inhospitable to life – such as extreme heat, cold or acidity. These organisms are considered important in the search for extraterrestrial life because (a) they appear "primitive", and (b) because environments such as thermal springs, or undersea vents, were probably more akin to general conditions on the early Earth than the more normal environments we are familiar with.

5) Suppose that a small asteroid or comet – like the one that struck an uninhabited area of Siberia in the early 20^{th} century – were to hit the Earth next year. What is the probability that it would wipe out a major city? [hint: to do this you need to estimate the fraction of the Earth's surface that is covered by cities. There is no single right answer, so be very careful to state your assumptions clearly.]

The population of the Earth is about 6 billion. Let's assume that half of that number live in cities, and that the average city has 1 million inhabitants. In that case, there are 3,000 cities. The land area of Denver is about 400 km^2. So the total land area covered by cities is:

$$400\ km^2 \times 3{,}000 = 1.2 \text{ million square km}$$

The total surface area of the Earth is $4\pi R^2 = 515$ million square km. So the fraction covered by cities is: 2×10^{-3} or 0.2%. This is also the probability that an asteroid, hitting at a random point on the surface, would hit a city. Unlike in the movies (where asteroids unfailing target New York!) even a serious impact would be unlikely to strike a highly populated area.

Note: to do this sort of question you need to make reasonable assumptions or estimates about, for example, how large a typical city is. One can look up numbers on the web or in books, but getting a feel for making estimates is a useful skill in many areas.