Final Exam

Astronomy 105 -- Earth in its Cosmic Context
December 15, 2018

This is a 3-hour exam. **No Notes/Books/Devices are allowed**. Please give answers to order-of-magnitude precision, recall that 3x3~10, round to the nearest three or ten, and provide concise explanations of your reasoning throughout.

1. We've placed quite a bit of focus in this class on techniques for order-of-magnitude estimation. This problem draws on some of the numbers that you've been asked to memorize (to the nearest factor of 10 or 3) including the population of Earth, the number of ergs/gm in chemical fuel, the radius (and hence the area) of the Earth, and the flux of energy at Earth's surface in ergs/cm^2/sec from direct sunlight.

- (i) Based on food consumption *alone*, how many ergs are required per day to support one person? Briefly comment on how this estimate is constructed.

- (ii) Assuming that solar energy that reaches Earth can be captured and converted into food with an efficiency of 1%, what is the maximum population that Earth could theoretically support?

- (iii) Given that Earth's human population has been doubling every 50 years, how long (approximately) until the maximum population you've just calculated is reached?

- (iv) What are some important factors that affect the realism of the simple energy-based assessment that you have just carried out?

2. The planet Mars (which orbits at a distance of about 2x10^{13} cm from the Sun) is often in the news nowadays, as a consequence of Elon Musk's extravagant SpaceX plans for human visits, as well as because of the NASA's Insight lander's very recent successful touchdown on the Martian surface. Mars is surprisingly Earthlike in some respects, including the fact that it has a ~24-hour spin period. In the following questions, please include clear, accurate diagrams to support your answers, and neglect the potential complications provided by eclipses.

- (i) Mars has two small moons, Phobos and Deimos. Phobos has a short orbital period. It takes Phobos 8 hours to circle Mars, and so its "month" is only 1/3rd of a day! If we are standing on Mars' equator, and we observe Phobos directly overhead in its "full-moon" phase, what time of day is it?

- (ii) Because of its short orbital period, Phobos will set below the horizon soon after them time you worked out in part (i). At approximately what time of day will Phobos *next* rise above the horizon?

• (iii) Phobos exerts a gravitational force on each bit of mass within Mars that drops off in strength with distance from Phobos. The dust and rocks of the Martian surface are affected by Phobos' gravity in the same way that Earth's oceans are affected by Earth's Moon's gravity. That is, Mars experiences tides from Phobos. Based on what we know about how Earth's tides work, what can we say about how the distance between Mars and Phobos is changing? What is the ultimate fate of Phobos likely to be?

•(iv) Is it *ever* possible to observe Earth in the Martian sky at midnight? (Use a new diagram to illustrate your answer.)

• (v) Draw the phases that we can potentially observe for **Earth** from Mars, including their relative sizes (Use another diagram to illustrate your answer.)

• (vi) Earth's Moon rotates on its axis exactly one time for every orbit that it makes around Earth. As a result, we are never able to see the far side of the Moon from Earth's surface. If one has a sufficiently powerful telescope, is it possible to observe the far side of Earth's Moon from **Mars'** surface?

3. This problem deals with gravity. Imagine that engineers constructed a perfectly straight, perfectly insulated tunnel through the Earth from New Haven directly to Hawaii that reaches a maximum depth beneath the surface of over 1,000 kilometers.

• (i) If you were standing near the tunnel entrance, would it appear to drop straight down into the ground? Explain.

• (ii) Assuming that the tunnel tube is *perfectly smooth*, that is, assuming that the tunnel has everywhere a perfectly slippery surface with no friction, and assuming that there is also no air resistance in the tunnel, describe what would happen if you stepped into the tunnel. Specifically, indicate how your speed and position would vary as you slid inside the tunnel. Neglect Earth's rotation in constructing your answer.

• (iii) How would your motion in the tunnel change if there was a very tiny (but nevertheless finite) amount of air resistance to your motion? After a very long time, where would you be located?

• (iv) The acceleration of gravity at the surface of Earth is 1,000 cm/sec per sec, and the direction of the acceleration is toward the center of the Earth. Very roughly, if one were to use the tunnel to try to travel from New Haven to Hawaii, and assuming no friction or air resistance, how long would the trip take?

4. According to top500.org, as of last month, November 2018, the IBM Summit Supercomputer at Oak Ridge National Laboratory in Tennessee now holds the title of the world's most impressive calculating machine. It is capable of a staggering 3×10^{19} bit operations per second.

• (i) Given the food energy requirement of a human being, and given that Boltzmann's constant is roughly 10^{-16} ergs/K, could a single human brain theoretically out-compute the IBM Summit?

• (ii) If the Top500 list-topper doubles in computing power every 2 years, in what year is it (or was it) guaranteed that a machine will be capable of out-computing a human being?

• (iii) Give some well-reasoned arguments devoted to why the theoretical maximum human computation rate that you've computed might be significantly higher than the actual rate. Based on your arguments, estimate a reasonable actual computation rate for human intellectual processing.

• (iv) In reality, it's difficult to assign a utilitarian bit operation rate to the neural processing that goes on within the human mind. *The brain is not a digital computer*. Any comparisons such as the one you've made above are thus necessarily somewhat uncertain. What are potential warning signs that computers may be/will be overtaking us? This is potentially an important issue, so please take your answer seriously.

5. Life is certainly the most interesting aspect of Planet Earth, and indeed, is what sets Earth apart in the broader cosmic context.

• (i) Draw a clear schematic diagram of a living cell, that includes (and where relevant, shows the relations among) the following elements, each of which should be briefly defined and explained: DNA, base pairs, amino acids, ribosomes, proteins.

• (ii) At a fundamental level, what defines life? What are the essential basic operational features of life?

• (iii) Could a machine be alive, given the context of our definition? Can you think of a concrete example of a non-biological entity that might be reasonably considered to be alive? (No vague science-fiction type answers, please).

• (iv) How can the existence of life on Earth, which clearly has increased the amount of complexity and order at Earth's surface, be reconciled with the physical law of increase of entropy?