Test #1

You will have 60 minutes to complete this test.

Multiple Choice (2 points each – 15 questions)

1. The “black-body” temperature of a planet **(a) is set when the reradiated radiation equals the incoming radiation**; (b) falls unless the incoming radiation exceeds the reradiated radiation; (c) continues to rise as long as there is incoming radiation; (d) is set only by the IR radiation coming from the parent star
2. The tidal effects on a planet (a) decrease as the mass of the star increases; (b) decreases as the planet moves closer to the star; **(c) increases with decreasing distance from the star**; (d) increases with decreasing mass of the star. ***There was an issue with this problem, since I had given four erroneous choices initially.***
3. The existence of “ice ages” in the recent (few million years) past is believed in part to be due directly to (as in direct inputs into our ecosystem and climate): (a) changes in the energy output of the sun; (b) the rate of volcanic activity, and corresponding level of outgassing of CO_2 in the atmosphere; (c) the locations and sizes of the continents; **(d) the precession of Earth’s rotation axis and cyclic changes in Earth’s orbital ellipticity**.
4. The discovery of “hot Jovians” was surprising because (a) it was not surprising at all – planetary formation models predicted them; (b) these Jovians were all believed to be completely rocky (no gas) in nature; (c) these Jovian planets were orbiting around pulsars; **(d) these Jovians were located in places where they could not have formed – the gases that form them would not have been in solid form**.
5. One of the properties of life are that (a) it is carbon-based, using liquid water as a solvent, in an oxygen atmosphere; **(b) requires the preservation of its structure against thermodynamic degradation by consumption and reproduction or some other form of maintenance**; (c) must evolve so as to fill all the available ecological niches; (d) requires a temperature much like ours in order to sustain itself.
6. The Drake Equation in the end (a) tells us how prevalent life is throughout the Universe; (b) describes how long life would have to exist on a planet in order to reach intelligence; (c) explicitly assumes that the development of intelligence requires bipedalism; **(d) can tell us how far apart are various communicating civilizations from each other**.
7. The detection of extrasolar planets can now be done reproducibly through; (a) the observation of planets occulting their parent star; **(b) through time-lapsed observations of the motion of stars across the sky**; (c) through direct detection of planets in the infrared, radio, or visible spectrum; (d) through an astrologer or other oracle, working with a divining rod.
8. The human eye detects visible light, it is believed, because (a) the material in our retinas can interact only with visible light; (b) it was purely an accident of evolution – some fish hundreds of millions of years ago had such eyes, and we are stuck with them; (c) they could see in other parts of the spectrum, but over time they devolved so

that we can only see visible light; **(d) the local environment, and most of the atmosphere, is transparent to visible light but opaque to other radiation**.

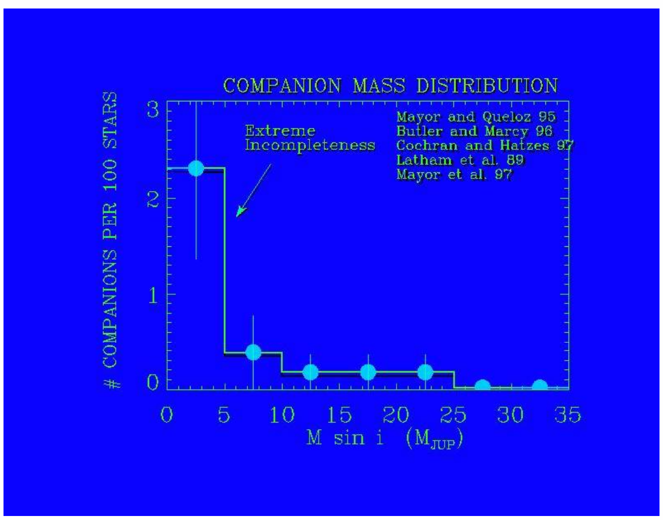
9. The presence of Jupiter, and its gravity, in the outer solar system is believed to (a) stabilize Earth's orbit against huge changes in its orbital shape; (b) protect the Earth from interstellar radiation; (c) keep rocky asteroids in the inner solar system from striking the earth; **(d) keep out nearly all the icy comets that would have struck the earth instead**.
10. The birth of life on Earth is believed to have required (a) a heavily reducing atmosphere; (b) the sun to be much fainter than it is today; **(c) the presence of organic materials from volcanoes or comets**; (d) the presence of an ozone layer to protect the surface from UV radiation.
11. Titan, a moon of Saturn, is not believed to have life using water because (a) it has organic compounds of the wrong type for using water (its hydrocarbons are not soluble in water); (b) there is very little water on Titan's surface; (c) there is much more liquid ammonia than water in the atmosphere and surface; **(d) water is a solid on Titan's surface**.
12. Enzymes are a type of protein catalyst that act to (a) speed up reactions; (b) synthesize organic compounds alone; (c) reduce the degrees of freedom of two or more reactants by attaching to them; **(d) (a) and (c)**.
13. The largest chunk of Earth's biological history took place in an (a) oxidizing atmosphere full of free oxygen; (b) the relatively quick development of multicelled, complicated organisms in Earth's history; **(c) an anoxic (no free O_2), neutral or reducing atmosphere with single-celled organisms**; (d) very cold atmosphere with sheets of ice spanning the globe.
14. The development of life was believed to be (a) the spontaneous arrangement of molecules until a group of them coalesced and became "living"; **(b) a semi-continuous process from a chemical ecology of competing, complicated, self-replicating molecules to "life" (somehow)**; (c) a result of something like the Miller-Urey experiment – reducing compounds + water + energy -> life (eventually); (d) the stable accumulation of organic compounds, such as amino acids, in the oceans until life eventually appeared.
15. On the shortest time scales, carbon dioxide is removed from Earth's atmosphere by (a) the carbonate-silicate cycle; (b) by dissolving into Earth's oceans; **(c) plants on land and in the sea**; (d) the construction of homes made of wood.

True/False Questions (2 points each – 10 questions)

1. The development of intelligent life could only have occurred now, because the galaxy is not much older than the sun (T/**F**).
2. The sun lies within the middle of a galactic spiral arm (T/**F**).
3. The most recent ice age (evidence of large-scale shifts in the environment) took place tens of thousands of years ago (T/**F**).
4. It is believed that one of the biggest bottlenecks to evolution on our planet was the development of multicelled life from single-celled life (**T**/F).
5. Intelligent life can develop on stars much more massive than the sun (T/**F**).
6. The presence of carbon in the universe is very sensitive to small changes in nuclear parameters in stellar nuclear reactions (**T**/F).
7. The Hart model results in a very wide CHZ (continuously habitable zone) for our sun – on the order of 1 AU (T/**F**).
8. Since the sun has the density of water, therefore the sun is a liquid (T/**F**).
9. The composition of Europa is believed to be mostly solid and liquid water by mass (T/**F**).
10. There is about as much carbon dioxide in Earth's atmosphere as there is in Mars's atmosphere (T/**F**).

Essay Questions

1. (10 points) Give the main reasons in which stars are different from planets – that is, what distinguishes a star from a planet?
   Planets are objects which cannot undergo long-term nuclear fusion, are not stellar corpses, and are formed from the remaining disk-like part of a central cloud (i.e., a few solar mass cloud may fragment into several clouds, which then collapse and form several disks that accrete into the central region – the central parts form stars, while the outer parts form into planets. A good evidence that stars and planets form differently is that the distribution of heavy planets cuts off at a few tens of Jupiter masses, while that of stars has a lower cutoff of a few hundredths of a solar mass).



Mass distribution histogram of planets, taken from Prof. Artymowicz's website, http://www.astro.su.se/~pawel/blois/talk_3.2.html.

2. (20 points) Describe in some detail the 2 main methods for searching for planets, and simply define another method for detecting planets. Also, what was the first extrasolar planet discovered, and what makes it so special? According to the old theory of planet formation, how did the gas giants form – you should describe the model in sufficient detail that you can show why Jupiter and Saturn have different compositions and masses from Uranus and Neptune.

The two main methods are *astrometry* (watching the gravitational wobble of stars as they move across the sky – their motion is not a straight line due to the gravitational effects of their planets) and *spectroscopy* (measuring the changing Doppler shift of stars as they move across the sky, due to the effects of planets). In both cases, the radius and velocity of the stellar wobble is $m/M << 1$ that of the planet's orbit and orbital velocity, where m is the planet mass and M is the star mass. Also, one can decompose the pattern of velocities or observed wobble to calculate the period and masses of the stars themselves. Astrometry – measuring periodic motion for decades of a star in its motion; spectroscopy – measuring slight periodic changes in Doppler shift of a star by passing starlight through a special gas and measuring precise changes in the gas's absorption. Other methods: measuring the change in light from transiting planets (transit photometry); measuring changes in light output from a "lensed" star due to gravitational lensing to locate a planet (gravitational microlensing); direct detection of planets (i.e., Darwin space probe).

First planet discovered – 51 Pegasi. Special because it was a "hot Jupiter" (so close to its sun, in this case, that T ~ 2000-3000 K), so how could it form there? Old theory – outer planets form in regions where volatile compounds (H_2O, NH_3, CH_4, etc.) are solid. First they form outer core of rocky materials and volatiles up to 10-20 Earth masses, after which they start accreting H and He before it all disappears. Second, the density of volatiles and H and He goes down with distance, so outer gas giants accreted volatiles more slowly than Jupiter and Saturn. Neptune and Uranus presumably formed far enough away that they could not accrete as much H and He as Jupiter and Saturn – hence they have SMALLER masses and a LARGER concentration of ammonia, water, methane, and other volatiles.

3. (20 points) Describe the carbonate-silicate cycle, and show how this is a negative feedback loop by raising and then lowering the temperature initially. What happens to the atmospheric carbon dioxide in both cases (raising and lowering temperature)?

In carbonate-silicate cycle, which takes place over millions of years, outgassing from volcanoes is a constant input of CO_2. From the process of weathering (temperature-dependent), carbonic acid from CO_2 (HCO_3^-) and calcium ion (Ca^{++}) are washed into the ocean. There, plankton forms shells from the calcium and carbonic acid, which then forms into limestones at the bottom of the ocean as these plankton die, and which then is subducted into the mantle and released again as volcanic CO_2.

Temperature increase (keeping volcanic activity, and CO_2 outgassing constant) -> more weathering (due to more water evaporation) -> more carbonic acid and calcium ions -> greater rate of limestone formation, leading to smaller atmospheric CO_2 concentration and lowered temperatures (due to reduced greenhouse effect).

Temperature decrease (keeping volcanic activity, and CO_2 outgassing constant) -> less weathering (due to decreased water evaporation) -> less carbonic acid and calcium ions -> smaller rate of limestone formation from plankton, leading to larger atmospheric CO_2 concentration and raised temperatures (due to increased greenhouse effect).

4. (10 points) Write down the simple (1961) Drake equation and describe all the terms in it.

Drake Equation: $N = R_* f_p n_e f_l f_i f_c L$**, where** R_* **is the rate of star formation on which intelligence life could develop,** f_p **is the fraction of stars with planets around them,** n_e **is the average number of Earth-like planets (i.e., planets in the CHZ) per planetary system,** f_l **is the probability that life will develop on such a planet,** f_i **is the probability that intelligence will develop on this planet,** f_c **is the probability that the intelligent species develops into a communicating civilization, and** L **is the average lifetime of this civilization.** N **is the total number of communicating civilizations in our galaxy.**

Math Questions

1. (5 points) There are 500 civilizations spread out uniformly through the disk of our galaxy. Our galactic disk can be thought of as a sheet 45,000 light-years in radius. What is the average separation between civilizations? Remember the formula for areal number density σ and average separation ℓ, $\ell = \sigma^{-1/2}$.

Recall that $\sigma = \frac{N}{A} = \frac{N}{\pi R^2} = 7.86 \times 10^{-8}$ **ly^{-2}. Then average separation**
$\ell = \left(7.86 \times 10^{-8}\right)^{-1/2} = 3570$ **light-years.**

2. (25 points) Now consider the question of the equilibrium sizes of GMCs (giant molecular clouds). The sizes of these clouds are determined by $G = 6.673\times10^{-11}$ kg^{-1} m^{3} s^{-2}, the mass density $\rho = 10^{-21}$ kg m^{-3}, and the local sound speed (taken with the temperature being 10 Kelvins), so that $c_s = 400$ m s^{-1}.

   a. (15 points) Using the prescription $G \equiv M^{-1}L^{3}T^{-2}$, $\rho \equiv ML^{-3}$, and $c_s \equiv LT^{-1}$, where M is a mass, L is a length, and T is a time, construct a length from these three variables using the prescription $R \equiv G^{\alpha}\rho^{\beta}c_s^{\gamma}$.

      The prescription is given by:

      $$M^{0}L^{1}T^{0} = \left(M^{-1}L^{3}T^{-2}\right)^{\alpha}\left(ML^{-3}\right)^{\beta}\left(LT^{-1}\right)^{\gamma}$$
      $$M^{0}L^{1}T^{0} = M^{-\alpha+\beta}L^{3\alpha-3\beta+\gamma}T^{-2\alpha-\gamma}$$

      Then the job is to match the exponents of M, L, and T simultaneously to get:

      $$0 = -\alpha + \beta$$
      $$1 = 3\alpha - 3\beta + \gamma$$
      $$0 = -2\alpha - \gamma$$

      Which results in $\alpha = -1/2$**,** $\beta = -1/2$**, and** $\gamma = 1$**. The size of this cloud is given by:** $R \equiv G^{-1/2}\rho^{-1/2}c_s$**.**

   b. (5 points) Using the above values of G, ρ, and c_s, calculate the radius R of this giant molecular cloud.

      Substitution of above quantities into this equation:

      $R \equiv (6.673\times10^{-11})^{-1/2}\left(10^{-21}\right)^{-1/2}(400) = 1.55\times10^{18}$ **m = 15.5 light-years.**

   c. (5 points) Using the mass density and assuming the cloud is a sphere, calculate the mass of the cloud (note that $M = \rho V$, where V is a volume and $V = \frac{4}{3}\pi R^{3}$ for a sphere).

      $M \equiv \frac{4}{3}\pi(1.55\times10^{18})^{3}\left(10^{-21}\right) = 1.55\times10^{34}$ **kg, or a few tens of thousands of solar masses. Thus, this exercise gives an idea of the dimensions and masses of giant molecular clouds.**