Homework 3 ,
Tuesday Jan 31
DUE Tuesday Feb 14 (beginning of class! -- You have TWO weeks)
ET Life, ASTRO/GEOL 3300, Tues/Thurs 2:00

The idea behind this homework assignment is that a walk through a model of our own solar system provides an appreciation of: 1) the immense size of our own local galactic neighborhood and the scale of astronomical distances; 2) the systematic variation in the composition of moons and planets in the solar system, and 3) implications of these factors in the search for extraterrestrial life. This is a natural follow-up to your last homework where I asked you to think about the scale of the solar system. Now that you are comfortable with that (I hope), we will take it to the next steps to get an idea of just how difficult it is to travel THAT FAR to the nearest star.

Astronomy students and faculty have worked with the University of Colorado to lay out a scale model solar system along the walkway from Fiske Planetarium northward to the Engineering complex almost to Colorado Avenue. The model is a memorial to astronaut Ellison Onizuka, a CU graduate who died in the explosion of the space shuttle Challenger in January of 1986. The Colorado Scale Model Solar System is on a scale of 1 to 10 billion (10^{10})! That is, for every meter in the scale model, there are 10 billion meters in the real solar system. Remind yourself of just how you worked through this in last Homework.

All of the sizes of the objects within the solar system (where possible), as well as the distances between them, have been reduced in this display by this same scale factor ($1:10^{10}$). As a result, the apparent angles between objects and the relative separations of objects in the model are accurate representations of how they would appear in the real solar system. Consider the first homework assignment you did, here it is!

HOWEVER, the model is unrealistic in one important respect: all of the planets have been arranged roughly in a straight line on the same side of the Sun, so the separation from one planet to the next is as small as it can possibly be. The last time all nine planets were lined up this well in the real solar system was the year 1596 BC (this was the true "Harmonic Convergence" for you astrology fans, and of course, nothing happened). In a more accurate representation, the planets would be scattered in all different directions (but still at their properly-scaled distances) from the Sun. For example, rather than along the sidewalk to the north of Fiske, Jupiter could be placed in Kittridge Commons to the south; Uranus might be found on the steps of Regent Hall, and Neptune in the Police Building by the parking lot. The inner rocky, or "terrestrial," planets (Mercury, Venus, Earth, and Mars) would still be in the vicinity of Fiske Planetarium, but could be in any direction from the model of the Sun.
For full credit on the questions below, please show your work (e.g. ratios used to determine answers).

1. The Terrestrial Planets
Read the information on the pyramid holding the model Sun in front of Fiske Planetarium. Note that the actual Sun is 1.4 million km in diameter, but on a 1 to 10 billion scale, it is only 14 cm across. Contemplate the vast amount of empty space that lies between these planets and the

Sun. But keep in mind that there's a whole lot more of "nothingness" to come!

1)Regaring the first four **terrestrial** or “rocky” planet:
a) Why are they called the terrestrial planets?
[“terra” is the latin for “Earth” …. so “terrestrial” is Earth-like]

b) Which of the them is most similar to Earth in size and composition?
[Venus is of very similar mass and radius. Given its location, we think it has a very similar bulk composition.]

c) Which of the three others is most Earth-like in Surface Temperature?
[Mars]

d) Which has the highest surface temperature and why?
[Venus, due to its very thick atmosphere that creates an intense greenhouse effect]

e) Which has the most similar rotation period to the Earth’s day?
[Mars rotation is nearly 24 hours.]

2) The real Earth orbits at 1 AU, about 150 million km from the Sun. This is the standard unit used when measuring distances within the Solar System.
a) What is the distance in AU between the Sun and Mercury?
0.381

b) Between the Sun and Venus?
0.7233

c) Between the Sun and Mars?
1.5236

d) Between Mercury and Venus?
0.3362 (just substracting from above)

e) Venus and Mars?
0.8003 (just substracting from above)

3) The Earth’s Moon is the furthest place that humans have traveled. It took 3 days to get there. As it turns out, the Moon is awesome and its surface has recorded a lot of Solar System history.
a) Estimate how far (in millimeters - in this scaled down system) that humans have ventured into space.
3.84 cm

b) What is the actual distance from Earth to the Moon in kilometers?

384,4000 km

c) Based on b) what was the average speed of the Apollo spacecraft in km/hour during its 3 day journey?

3 days = 72 hours

384,400 km/72 hours = 5339 km per hour

d.) Using the Apollo Astronauts speed, how long would it take humans to get to Jupiter?

Earth to Jupiter = (5.2 AU - 1.0 AU)*(1.49e8 km/AU)*(1/5339 km/hr)=117212 hours

=4883 days

= 13.3 years

4) Another way to describe distance is to use "light-time." This is the time it takes light, traveling at 300,000 km/second (or 670 million miles-per-hour for you folks addicted to English units!) to get from one place to another. Since light travels at the fastest speed possible in the universe, light-time represents the shortest time in which information can be sent from one place to another. Electromagnetic radiation (light energy), including sunlight and radio waves, takes 500 seconds (or 8.33 minutes) to reach the Earth; we say that the Earth is 8.33 light-minutes from the Sun. Remember, the light-minute is a measure of distance!

a) How many light-minutes is Venus from the Sun?

8.33 light minutes = 1 AU. Since Venus is 0.7233 AU from the Sun it is

0.7233 AU * 8.33 lightmin/AU = 6.025 lightmin

Over two years ago, the Mars Polar Lander set down on Mars. It was equipped with cameras and on-board computers that enable it to carry out functions after being pre-programmed from Earth.

(b) Why must this and other landers be pre-programmed, rather than being instructed remotely by an operator back on the Earth?

Mars is 1.5236 AU from the Sun, and 0.5236 AU from Earth (at its closest).

The minimum time delay in comminucation is then:

0.5236 AU * 8.33 lightmin/AU * 2 = 8.723 minutes (the extra 2 is for round-trip time).

4) On Earth, temperature and pressure conditions are such that water (H_2O) can be a liquid, a solid, and a gas. The temperature and pressure conditions on other planets can be very different from the Earth. Like the atmosphere of the Earth, the atmosphere of Mars contains carbon dioxide (CO_2) gas. Also like Earth, Mars has icy polar caps. But unlike Earth, the polar caps of Mars also contain CO_2 ice, known as "dry ice."

(a) Can water exist as a liquid at Mars today? Justify your answer.

Not really, as the thin atmosphere leads to very low pressures, where water is only stable in gas and solid form.

6) The "habitable zone" around a star is commonly defined as the region over which liquid water can be stable on the surface of a terrestrial planet. To estimate the width of the habitable zone in other solar systems, we can use our own solar system as a guide.

(a) Based on what you observe in the scale model of the solar system and knowing that Earth is habitable, **between the orbits of which two planets might liquid water be stable in our solar system?**

Between the orbits of Venus and Mars.

The Outer Planets and their Moons

As you cross under Regent Drive heading for Jupiter, you'll also be crossing the region of the asteroid belt, where thousands of "planetoids" or "minor planets" can be found crossing your path. The very largest of these, Ceres, is 760 km in diameter. At the scale of our solar system model, Ceres would be the size of a speck of dust. After you cross the "Frost Line" of the solar system, you will now enter the realm of the gas giant (or Jovian) planets, which are composed principally of hydrogen and helium. They also contain water (H_2O), ammonia (NH_3), methane (CH_4), and other compounds. They are believed to contain rock and metal deep in their cores.

7). Jupiter contains over 70% of all the mass in the solar system apart from the Sun, but its mass is still < 1/1000 that of the Sun itself.

(a) How many times more massive is Jupiter than the Earth?

Jupiter is 1898e24 kg   Earth=5.97e24 kg

Jupiter = 1898e24/5.97e24 ~ 318 Earth Masses.

(b) How does the temperature of Jupiter's cloud tops compare with the surface temperatures of the inner planets?

Much colder... colder even than Mars.

(c) Explain how Jupiter's great mass is still consistent with its hydrogen-rich composition and low density.

Jupiter's great mass allows it to retain very light gases due to its strong gravity. It is also beyond the Solar Systems snow/frost line.

(d) Io is a moon of Jupiter, and orbits Jupiter at about the same distance as our Moon orbits the Earth. How do you think the gravitational pull of Jupiter on Io (Jupiter's TIDE on its moon) compare to the gravitational pull of Earth on our Moon?

Jupiter's great mass causes extreme tides on Io - as its gravitational pull is so much stronger.

8) Our next stop is the beautiful ringed planet Saturn, the most distant planet that can be seen

from Earth without a telescope (i.e. with the naked eye).
(a) When Jupiter and Saturn are aligned on the same side of the Sun, what is the distance in AU between these two planets?
Jupiter is at 5.2026 AU, Saturn at 9.5719 AU
9.5719-5.2026 = 4.37 AU *1.49e8 km/AU = 655e6 km.

(b) Saturn's large moon Titan has a thick atmosphere of nitrogen (N_2) and methane (CH_4). Why might Titan have such a thick atmosphere, even though Jupiter's larger moon Ganymede does not?
Titan is larger (much larger) and is 4 AU further from the Sun. More gravity, and lower temperatures.

9) Continue the journey on to Uranus and then Neptune. As you do, ponder the vast expanse of space through which you are passing.
(a) How do the sizes of Uranus and Neptune compare?
Similar to each other in mass and diameter. Uranus is 86.6e24 kg and 50,000 km, while Neptune is 102.4e24 kg and 49,500 km.

(b) What does the blue color of these gas giant planets have to do with their great distance from the Sun?
Abundance of methane and ammonia ices that are stable in cold temperatures.

(c) What four kinds of ice might you expect to find on Triton's frigid surface?
Water ice, ammonia, methane and some others.

(d) Triton has a very thin atmosphere compared to that of Titan. Why might this be so?
It could have been lost, or frozen (condensed) to its surface.

Pluto (the Dwarf Planet since it's not really a planet) and Beyond.
10) Make the final walk to Pluto. There you will be standing 0.5 km (0.3 mi) from where you started your journey (exhausting.. I know). Pluto has a more elliptical orbit than the planets, with a distance at perihelion (its closest point to the Sun) of about 30 AU and a distance at aphelion (its farthest point from the Sun) of about 48 AU.

(a) You may have been surprised by how soon you arrived at Pluto after leaving Neptune. Read the plaque, and explain why the walk was relatively short.
It has a very eccentric orbit, so at times is even within the orbit of Neptune.

(b) Scientists are concerned that to study Pluto's nitrogen-rich atmosphere, a spacecraft must

arrive at Pluto before the year 2020 (CU helped build this spacecraft with Ball Aerospace located near the corner of Arapahoe and Foothills Parkway and it's currently on its way to the outer solar system and Pluto!). Explain why we need to get there before 2020.
New Horizons need to get there before Pluto has moved even further from the Sun, to colder temperatures which might result in its atmosphere condensing and freezing on its surface.

(c) Pluto is similar in size and composition to Neptune's moon Triton. What might this say about the origins of Pluto and Triton?
It has been speculated that Triton was formed near Pluto, but was eventually captured by Neptune.

Although we have reached the edge of the solar system as is normally visible through a telescope, that doesn't mean that the solar system actually ends here, nor does humankind's exploration of the solar system end here. Down on the other side of Boulder Creek to your north, at 97 AU from the model Sun, Voyager 2 is still traveling outwards towards the stars at a speed of 56,000 km per hour, and still sending back data to Earth. In 2000 years, Comet Hale-Bopp will reach its furthest distance from the Sun, just north of the city of Boulder near Heil Rance (off 36) at our scale. Comet Hyakutake, visible from Earth in 1996, will require 23,000 years more to reach its greatest distance from the Sun, 24 km to the north near the town of Lyons. Beyond Hyakutake's orbit are the great repositories of comets-yet-to-be: the Kuiper Belt and the Oort cloud, collections of billions of microscopic (at our scale) "snowy dirtballs" scattered over the space out to the Wyoming border and beyond. Each of these is slowly orbiting our grapefruit-sized model of the Sun, waiting for a passing star to jog it into a million-year plunge into the inner solar system. One of these might strike any of the moons or planets, including the Earth.

c) And there is where our solar system really ends. Beyond, you'll find nothing but (mostly) empty space until you encounter the triple star system of Alpha Centauri, including the closest star Proxima Centauri. In our model solar system, the Alpha Centauri system is about 3990 km away from our model Sun.

(a) Continuing our walk toward the north, in what geographic area would the model Centauri system be located on a map of the Earth?
Canada. British Columbia. The other direction take us to sunny Honduras.

(b) How many years will it take light from our Sun to reach the Alpha Centauri system?
4.3 years

(c) At the speed of the Voyager spacecraft, how many years would it take to reach the Alpha Centauri system?
Moving at 56,000 km/hour, needing to cover 4.3 ly * (9.5e12 km/ly)
=4.08e13km/56000 km/hr = 730e6 hours = 83,215 years.

(d) Explain based on what you have just covered in this homework assignment why many scientists consider radio signals, which travel at the speed of light, to be the only realistic means for us to rapidly communicate with intelligent life if it exists on planets around other stars.

Light is the faster way to move information, and radio is one form of light. Otherwise it will take too long.