PHYS 1040: Solution
Assignment #2, Spring 2008

1: My semester project rules!

Many of you have wondered if you have to stick with the semester project that you pick now, and whether you can change your mind later after we've learned about a lot more astronomy stuff. The answer is *yes, you can change your mind later!* The point in this exercise is to get you thinking about the project, and help me make sure we aren't going to have 50 projects about Pluto's moon, Charon. You can stick with the project you tell me here, or if you change your mind later, try something new!

If *I* were going to make a poster with you, I'd make a poster about measuring the scale of the Universe from my backyard (a project I am working on with some amateur astronomy friends of mine). We all can look up the size of the Earth and the distance to the Moon, and the scale of Jupiter's orbit. But how were these measurements first made? It is possible, using simple devices you build in your kitchen and observations from your backyard, to measure the scale of the Universe yourself!

2: Kepler's Laws are very useful!

Kepler taught us that the time it takes an object to orbit its parent body is related to the distance away from the source of gravity that causes the orbit. This is known as *Kepler's Third Law of Planetary Motion.* It is generally written as

$$P_{orb}^2 \propto a^3$$

where P_{orb} is the orbital period, and a is the semi-major axis of the orbit (a is the radius of the orbit for circular orbits; for elliptical orbits a is the distance from the center of the orbit to the edge measured along the long axis of the ellipse).

In this case, you are considering a star orbiting the center of the Andromeda Galaxy. The semi-major axis a is simply the distance from the center of the galaxy to your star. From this, you can estimate P_{orb}, the time it takes to orbit the center of the galaxy.

3: That's some mighty big Binoculars!

The Large Binocular Telescope (LBT) uses two mirrors side by side, just like a pair of binoculars. This will give astronomers an unprecedented view of the Cosmos.

To determine the smallest object the LBT can see on the Moon, we follow the example we did in class of the Hubble Space Telescope where the size we can resolve is given be

$$L \simeq R \cdot \frac{\lambda}{D}$$

We use all the same values, except we use D for the LBT rather than HST:

$$\begin{aligned} L &= \text{what we are looking for} \\ R &= \text{distance to Moon} = 3.84 \times 10^8\text{m} \\ \lambda &= \text{wavelength of visible light} = 5.0 \times 10^{-7}\text{m} \\ D &= \text{diameter of LBT telescope} = 11.8\text{m} \end{aligned}$$

Putting this all together:

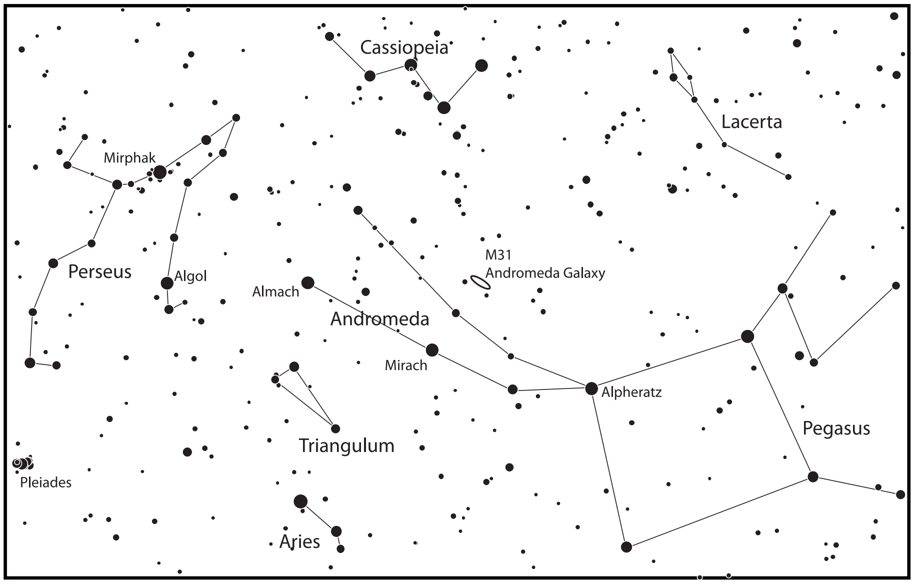
$$L \simeq \frac{(3.84 \times 10^8\text{m}) \cdot (5.0 \times 10^{-7}\text{m})}{11.8\text{m}} = 16.3\text{m}$$

In reality the capability of the LBT is limited to much worse resolution than this because the Earth's atmosphere blurs our vision. This is one reason why the Hubble Space Telescope was built — to get above the Earth's atmosphere.

4: Where's that comet headed?
Sleep is for the weak! Sleep is for the weak! Just keep telling yourself that over and over again. Your discovery of *Comet You* has everyone excited. People and astronomy classes around the world are spending countless hours every night starting up at the sky, studying what is quite probably the finest comet ever discovered. But where is it going?

To discover the motion of the comet, you look at the spectrum of the comet's gases. Since the comet is in motion the spectral lines will be shifted as a result of the *Doppler Effect.* If the comet is moving *toward* you, the Doppler shift will move all the spectral lines toward the *blue* part of the spectrum. If the comet is moving *away* from you, the Doppler shift will move all the spectral lines toward the *red* part of the spectrum.

5: Taking the Temperature of the Stars The sky chart showing you how to find γ Andromeda (Almach) is shown below. While you are in the area, take a look at the Andromeda Galaxy (M31), located nearby.



The color of a star (we will eventually equate this with the *spectral type*) can be related to the temperature of the star: stars with colors in the blue and violet end of the spectrum can have temperatures as high as 50000°C, while red stars can have temperatures as low as 3500°C. Our own Sun only has a surface temperature of $\sim$ 5000°C. The blue-green star in γ Andromeda is likely hotter than the yellow-orange star for this reason.

6: Cooking up some atoms
In the Early Universe, the Cosmos was very hot and dense, which prevented atoms as we know them from forming. Just prior to recombination, the hot energetic environment kept electrons from binding together with nuclei to form atoms. As a result, the Universe was filled with a soup of free electrons and free atomic nuclei. These particles are all *electrically charged* and called *ions.* Photons like to interact with ions, and cannot travel very far when there are lots of ions around; they are easily distracted.

The Universe continued to cool, and eventually the temperature was low enough that electrons could bind to nuclei and stay bound, forming *neutral atoms.* The formation of these atoms is called *recombination*, and occurred about 300,000 years after the Big Bang.

With most of the ions binding together to form atoms, the photons were suddenly able to move without being distracted. We say that the *Universe became transparent*, and the photons *decoupled* from the matter; this is known as *decoupling*, and the photons from this time are seen on Earth as the Cosmic Microwave Background.