ASTRO190 HOMEWORK #3. DUE Monday February 4. Problem 3 may be difficult, so start early. Extensions will be granted if you see me on February 1 or before.

You will find the relevant reading material in Chapters 1 and 2 as well as my notes, *faculty.washington.edu/balick/astro190/Homework_TermPapers_Lectures/.* I welcome you to contact me (543-7683; balick@uw.edu) if you are stymied.

1. (3 pts) Distances & Mapping the Cosmos (see notes and Chapter 3)
a. What's a standard candle and how does it enable us to derive distances?
b. What standard candle is used measure distances of ~10 billion light years? Why?
c. Why were good distance measurements to galaxies so important for Hubble as he tried to estimate their masses?
d. Hubble's first measurements of the Hubble Law implied that the age of the Universe is a mere 2 billion years – far less than the ages of most stars and even the Earth. That age estimate was soon revised by Walter Baade. What changed? (last part of Chap. 2)

2 (3 pts). Until the late 1990s the best evidence suggested that the Universe is open. (see notes and Chapter 2)
a. Describe three of the more important characteristics of an "open universe".
b. What's the difference between "luminous mass" and "gravitational mass"?
c. On page 99 of the text the authors state: "…our measurements of the density of matter are always too low". The word 'always' is wrong. Argue that Sandage's method (extending the Hubble diagram) captures all of the mass no matter what its form, including dark matter.

3 (4 pts). *This problem may well be the most challenging of all homework questions in the course. Do this problem using the worksheet at the end of this assignment. (Please be sure that your name is on it when you submit it.) Start early! Contact me for help.*

Lets warm up. Imagine an expanding universe with observers randomly placed on a gigantic and rapidly stretching trampoline. Each observer sees all of the others moving away from them with a speed that increases with the distance to other observers.

If any model of cosmology is to be tenable then all observers must separately test it (at any instant of cosmic time) and see if they agree on its ***form***. That is, the model must apply universally. Thus the guiding question is this:

Is the Hubble Law universal?

An astronomer in the Milky Way ("MW"), Eddy Hubble, identifies four galaxies, A, B, C, and D, in a highly magnified image of a small field in the sky. He measures their distances and recession speeds. The results are shown in the table in the worksheet below. Note that there are small measurement errors built into the data!
a. Make a "Hubble plot" of recession speed versus distance just as Eddy Hubble would have.
b. Show that four contemporary astronomers on galaxies A, B, C, and D who observe each other's galaxies and the Milky Way will derive the Hubble Law with the same slope as Eddy Hubble's. That is, show that each plot has a universal form.

Notes on question 3

Use the worksheet on the next page (with your name on it) to submit all five Hubble plots, one per observer. Please take a photo of the sheet of completed graphs and email it to me. Please be sure that your name is on it.

Comment: Simply showing five plots doesn't reveal the steps that you took to derive your results. In order that I can provide some feedback to you, please separately summarize how you reached your conclusion. For example, it could be very useful for you to make a table showing a table like that in the worksheet that lists relative distances and speeds of each galaxy measured by observers on galaxies A, B., C, and D. Alternately, describe the data analysis process that you used.

Assuming that the galaxy data are fitted by a single line, then their relative distances (motions) are found by subtracting the distances (speeds) of pairs of galaxies.

Hint: It helps to draw a picture, like this one for the observer in the MW

```
            MW-----C---------B---------------A------D
Dist         0     250       600            1300   1650      mega lightyears (Mly)
Speed        0    5800     14000           28000  36000      km/sec
```

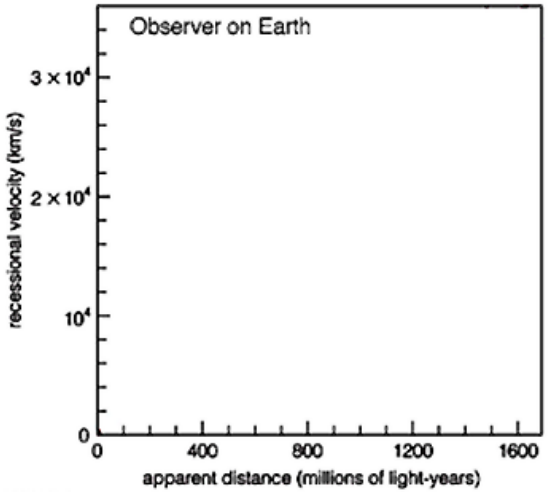
Then subtract all pairs of distances and speeds.

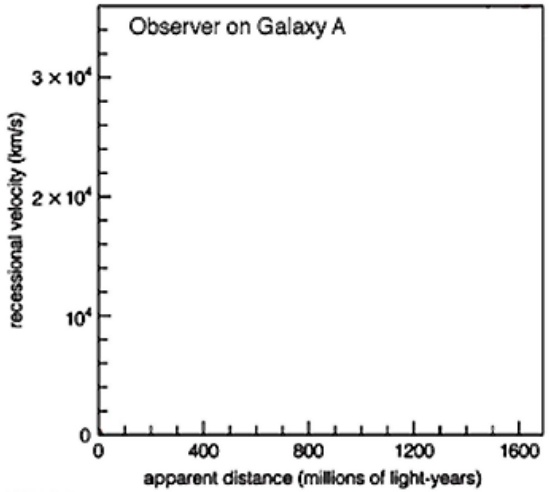
An example is given below for observer on Galaxy A.

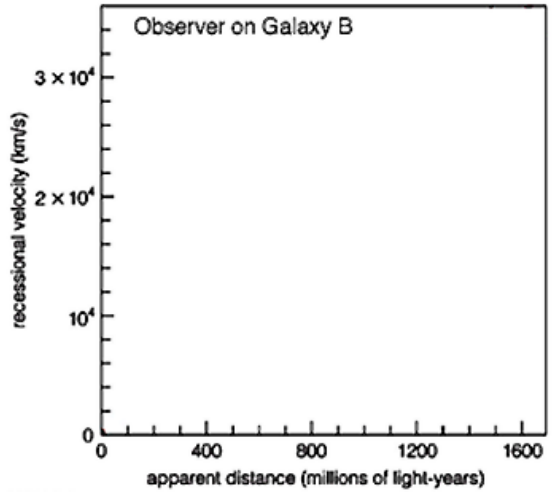
```
      Relative Distances                        Relative Speeds
    millions of lightyears                       kilometers/sec
      MW     A     B     C     D            MW     A     B     C     D
MW     0  1300   600   250  1650    MW      0 28000 14000  5800 36000
 A  1300     0   700  1050   350     A  28000     0 14000 22200  8000
 B   ---   ---     0   ---   ---     B    ---   ---     0   ---   ---
 C   ---   ---   ---     0   ---     C    ---   ---   ---     0   ---
 D   ---   ---   ---   ---     0     D    ---   ---   ---   ---     0
```

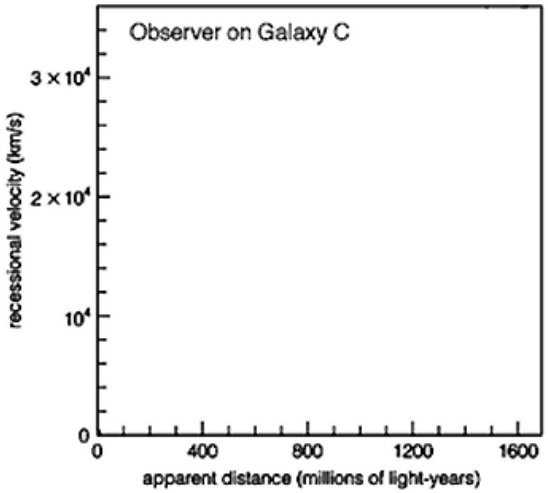
Make plots of these points for each galaxy (next page) and show that the slope of the Line through the points is the same in all of them. Tyfn in your plots (with your name).

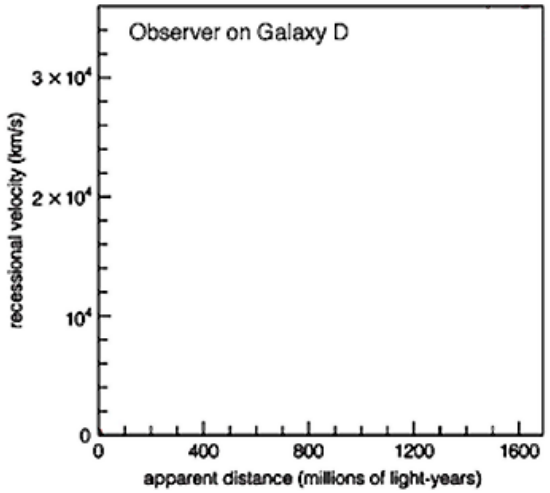
Your Name:











Distances and Speeds of Galaxies A, B. C, D, as seen from the Milky Way by Edwin Hubble

Galaxy	A	B	C	D	MW
Apaprent Distance (10^6 light years)	1300	600	250	1650	0
Recession Speed (km/s)	28000	14000	6000	36000	0