Homework 3

AST 301, Sections 46845 and 46850, Spring 2016

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Due Tuesday, April 5, 2016

Note: You will need to read ahead in Lecture 17 to do one of the multiple choice questions.

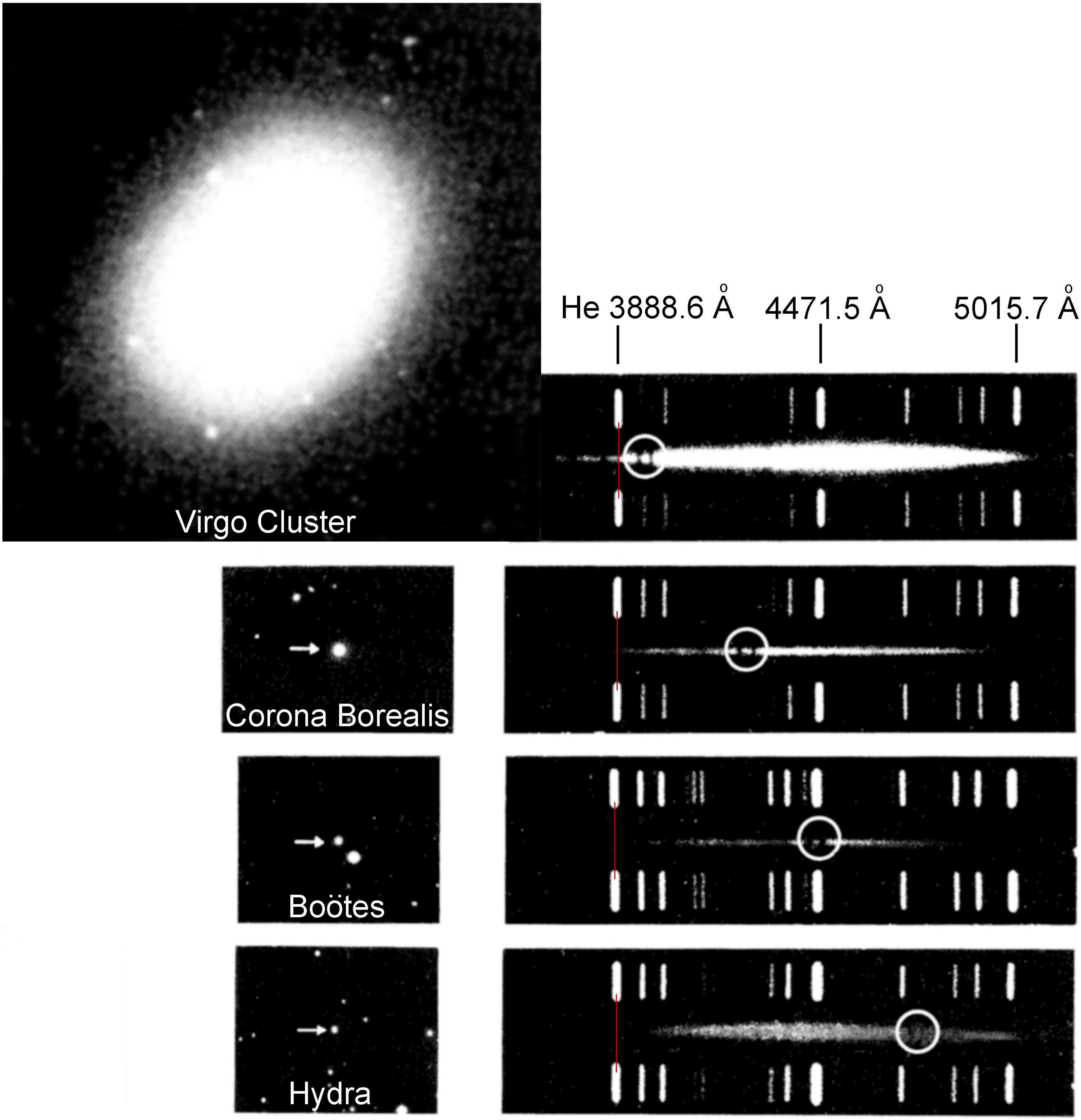
A. – THE AGE OF THE UNIVERSE

In this homework, believe it or not, you are going to estimate the age of the Universe. But don't worry, I will guide you through the arithmetic. Astronomers do this job in more or less the same way; they just use more data and data of higher quality, for example, from the Hubble Space Telescope. And they use more ways to get distances than you will use below. But this exercise is entirely realistic.

Let's pretend that you just returned from an observing run at McDonald Observatory in West Texas. There, you took pictures and spectra of the brightest galaxies in four clusters of galaxies, Virgo, Corona Borealis, Boötes, and Hydra. The pictures and spectra are on reproduced on the next page of this homework assignment. There is a version of this figure in the Cosmology chapter of the textbook, but it is more convenient for you and the TAs if I give everybody the same copy of the figure. This also makes you more independent of the textbook. **Note: The book gives answers to some parts of this homework. Ignore them and derive your own answers. It is OK to compare your answers to the book to help you to make no mistakes. But don't fiddle your numbers to agree with the book. Also, if you work together with other students, please make your own measurements. If we find that two students get exactly the same numbers, we will give zero points to both students. This is IMPORTANT.**

First, let's estimate the distance to each galaxy. It is a good approximation to assume that they are all the same size. Also, we assume that the pictures are printed at the same magnification. Now, if you measure the size of the image of each galaxy (it is best to use a millimeter ruler), and if that galaxy looks (for example) 20 times smaller than the Virgo galaxy, then it is 20 times farther away than Virgo. Somebody has already measured that the distance to Virgo is 17 Mpc. Notice that some galaxies are round and others are not. So, measure the longest diameter of each galaxy (in mm) and write the answer in the second column of the table on page 3. Then measure the shortest diameter and write it in the third column. Average the two measurements and write the answer in the fourth column. Note: You have to be very careful with the distant galaxies, because they are tiny. If you try to measure sizes accurate to 0.1 mm, you will probably manage an accuracy of about ± 0.2 mm. This is good enough. Be sure to hand in with the rest of your homework the printout of the figure that you used to do your work. (5 points)

Now estimate the distance to each galaxy from its size, from the size of the Virgo galaxy, and from the distance to Virgo. Write the answer in the fifth column of the table. (5 points)



Next you need to measure the redshift of each galaxy. You do this using the spectra, by measuring the positions of the strongest spectral lines, the H and K absorption lines of Calcium. To help you later, you have already circled these lines in each spectrum. You can see them near the left (blue) end of the Virgo spectrum and then progressively farther to the right (red) in each succeeding spectrum. This means that the galaxies are already arranged (top to bottom) in order of increasing redshift.

Galaxy in	Longest diameter (mm)	Shortest diameter (mm)	Average diameter (mm)	Distance (Mpc)	observed H line (Å)	redshift in (Å)	redshift (km/s)
Virgo	______	______	______	17	______	______	______
Cor Bor	______	______	______	______	______	______	______
Boötes	______	______	______	______	______	______	______
Hydra	______	______	______	______	______	______	______

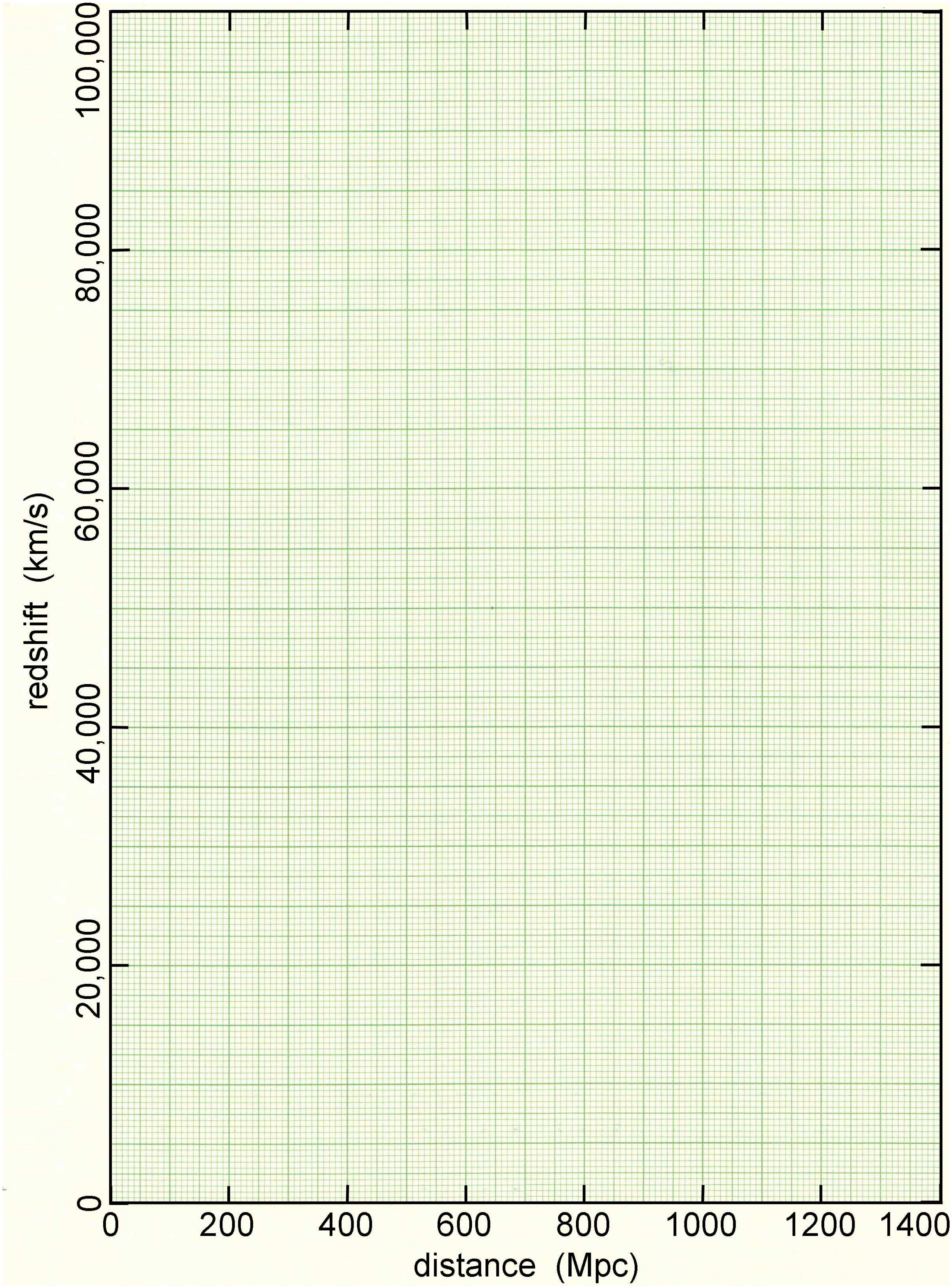
In the spectra, wavelength increases (the color gets redder) toward the right. You may wonder how astronomers know what wavelength is represented at each position in a spectrum. The answer is that they take an almost-simultaneous spectrum of an emission-line source – a lamp like the one that we looked at in class. Here, the comparison spectrum is the emission-line spectrum of helium ("He") gas. It is exposed above and below each galaxy spectrum. The wavelengths of three lines are labeled. So, if you print the figure, you can measure how widely light of different colors is spread out on the print. This is called the "dispersion" of the spectrum. You can use any two or all three of the comparison lines to measure an average dispersion. Your answer is ________ Å per mm on the printout. (2 points).

Now you are ready to measure the redshifts of the four galaxies. Your measurements are helped by notes that you made during the observing run: You already drew a red line on each spectrum thorough the center of the He 3888.6 Å line. So you can measure the position of the H and K lines horizontally from the red line and use the dispersion measurement to get the wavelength of the lines in each spectrum. For this exercise, it is good enough to use just one line; that is, the bluer H line. Measure the horizontal separation of the H line from the red line that marks the position of 3886.6 Å. Now, convert this separation from mm to Ångstroms using the dispersion that you measured above. Then write the observed (redshifted) wavelength of the H line in the "observed H line" column of the table. (3 points)

The rest-frame wavelength of the H line is 3933.7 Å. Write the redshift of each galaxy in Å in column 7 ("redshift in Å") of the table. (5 points)

The velocity in km/s is equal to the redshift in Å divided by the rest wavelength of the Ca line and multiplied by the speed of light. The speed of light is 300,000 km/s. Calculate the redshift of each galaxy in km/s and write the answer in the last column of the table (5 points) You may want to compare your answers with the values given in the book, but don't cook your measurements to get those numbers. Just do your best to measure them directly.

Now you can plot a "Hubble diagram" which shows how quickly the Universe is expanding. The necessary graph paper is on the next page. Make a plot of redshift in km/s against distance in Mpc. (5 points)


100,000
80,000
60,000
40,000
20,000
0
redshift (km/s)
0
200
400
600
800
1000
1200
1400
distance (Mpc)

This plot shows that more distant galaxies have higher redshifts in km/s corresponding to a faster expansion of the Universe. Draw the best straight line that you can through the collection of points. You will find that they are not in a perfect line, partly because of measurement errors (our procedure is pretty crude) and partly because there is no guarantee that the pictures are exactly the same in exposure time and magnification. Just draw the best average line you can. **Make sure that it goes through zero velocity at zero distance.** (5 points)

You can now calculate the Hubble constant, that is, the number of km/s of expansion of the Universe per Mpc of distance. You can get this from any point on the line. Be sure to keep the units, which are km/s/Mpc.

The Hubble constant is: (7 points)

Finally, you are ready to estimate the age of the Universe. This is, roughly speaking, the time that it has taken each galaxy to get to its present distance from us at its present velocity. Why? Because the Universe began in a Big Bang, when everything (including us and all of the present four galaxies) were together in one place. So the age is given, for example, by the distance you have gone if your velocity is 50,000 km/s divided by 50,000 km/s. In other words, the age of the Universe is approximately 1/(Hubble constant). Calculate the age of the Universe in years. Use the average line that you drew, not any individual cluster – this gives you a more accurate answer. You need to know that 1 pc is 3.09×10^{16} m and that 1 year is 3.16×10^{7} seconds (you can figure this out for yourself). In this part of the homework, the main thing to watch out for is units: make sure that you carry the units through every step of your calculation. The answer is:

The age of the Universe is: (8 points)

The true age is slightly shorter if there is enough matter in the Universe to slow down the expansion. But you should get within a factor of 2 of the right answer. It's not every day that you can calculate the age of the Universe to a factor of two! Astronomers do it essentially the same way that you have done it, only they use many more spectra and they use more accurate measuring machines or computer programs.

B. Exam-style multiple-choice questions. For each question, circle the correct answer. (5 points each)

1. In the Milky Way galaxy, young stars – including the Sun – have orbits that
   (A) are nearly circular in the disk of the Galaxy.
   (B) slowly spiral in to the center of the Galaxy.
   (C) slowly spiral out to the outside of the Galaxy.
   (D) are random but confined to the disk plane.
   (E) are randomly oriented.

2. Which of these is correct?
   (A) The Milky Way looks almost uniformly bright around the sky, so we must be at the center.
   (B) The center of the Milky Way is visible through an eyepiece at a large telescope.
   (C) The Sun is one of the oldest stars in the Milky Way.
   (D) We live in the suburbs of the Milky Way; the Sun is an average star among billions.
   (E) The Milky Way is a 2-armed spiral; we can't see that because we live inside it.

3. According to the Hubble classification scheme, an Sc galaxy has
   (A) a large central bulge and tightly wound spiral arms.
   (B) a small central bulge and loosely would spiral arms.
   (C) a round or elliptical appearance with a smooth light distribution.
   (D) an irregular shape with no obvious spiral arms.
   (E) a featureless disk embedded in an almost spherical, smooth halo.

4. According to the Hubble classification scheme, an S0 galaxy has
   (A) a large central bulge and tightly wound spiral arms.
   (B) a small central bulge and loosely would spiral arms.
   (C) a round or elliptical appearance with a smooth light distribution.
   (D) an irregular shape with no obvious spiral arms.
   (E) a featureless disk embedded in an almost spherical, smooth halo.

5. Which of these **is not** a good tracer of spiral structure?
   (A) young stars
   (B) star-forming molecular clouds
   (C) globular clusters
   (D) cool hydrogen gas
   (E) 20 $M_\odot$ stars

6. If star formation switched off in a spiral galaxy, which part of it would get fainter?
   (A) the bulge
   (B) the disk
   (C) the halo
   (D) the dark matter
   (E) the globular clusters

7. What is the essential difference between the formation of spiral and elliptical galaxies?
   (A) Random motions of stars are larger in ellipticals.
   (B) Spiral galaxies had a more recent tidal encounter with another galaxy.
   (C) Ellipticals form stars before they collapse; spirals form stars after they collapse.
   (D) Spiral galaxies rotate faster.
   (E) Ellipticals had a more recent violent encounter with another galaxy.

8. Why – mainly – do people measure the redshifts of galaxies?
   (A) To find their distances.
   (B) To find out what kind of stars they contain.
   (C) To get big grants from the National Science Foundation.
   (D) To see whether they are ellipticals or spirals.
   (E) To measure their luminosities.

9. The Milky Way and the Andromeda Galaxy are moving toward each other at more than 50 km/s. What will happen when they collide?
   (A) If humans still exist, they will be wiped out.
   (B) Nothing: they will just pass through each other and fly apart unchanged, because stars are too far apart to collide.
   (C) Lots of fireworks: many stars in our Galaxy will collide with stars in Andromeda.
   (D) They will tidally distort each other and may stick together and form a giant elliptical galaxy.
   (E) Each will come out of the collision as a wreck – as an irregular galaxy.

10. The temperature of the background radiation is almost the same in all directions.
    (A) This is surprising, because the radiation from opposite directions in the sky is coming from places that, given redshifts of galaxies there, are beyond each other's light travel horizon.
    (B) This is expected, because the Big Bang was a very homogeneous explosion.
    (C) This was a measurement error in early observations that are now discredited.
    (D) The statement is not true: the temperature shows large fluctuations all over the sky.
    (E) None of the above.