Observational Cosmology: Homework No.5

*Student ID:*__________ *Name:*__________

Note:

- Read the questions carefully, and write all the solutions on the answer sheets.
- All the calculations should be formulated step by step and all the explanations should be clear. Calculation with only a number as the result will get **0** score.
- Be free to search for the references on the internet or to ask others for help, but cite them carefully and make sure that you understand the answer.
- The "Optional" questions are not necessary to be done. Finish them if possible to earn additional scores.

1. (Classification of the Galaxies) Galaxies always have different looks, but based on their common properties, we are able to classify them into several types.

   (1) What are the four major types of galaxies? How do they differ in their look? Which type is called the "early type" and which is called the "late type"? Draw a simple Hubble Tuning Fork to put all the types in order.

   (2) Look at the galaxies in Figure 1, and classify them according to the Hubble scheme.

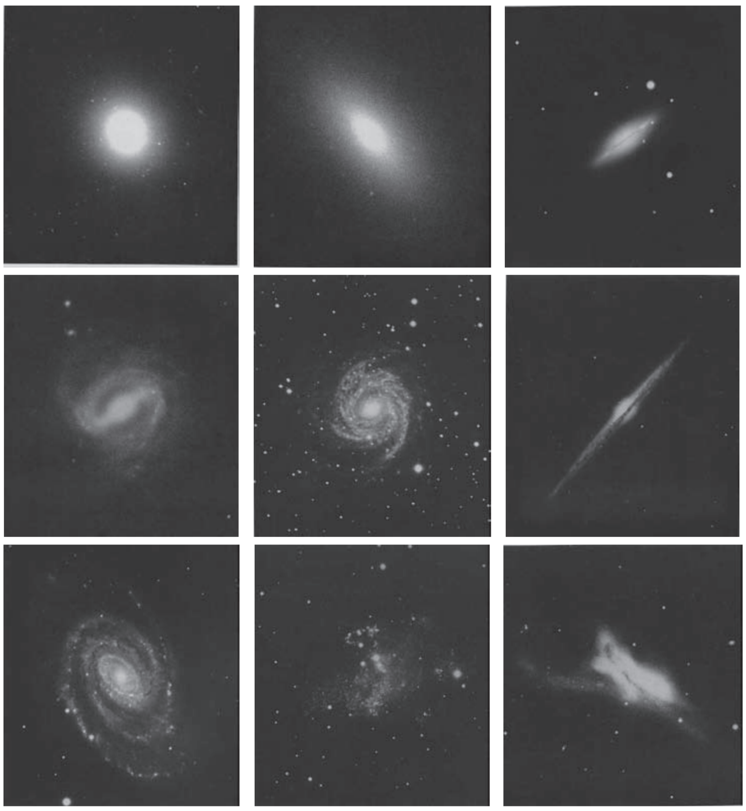

Figure 1: Classification of the galaxies.

   (3) What are the differences between the sub-classes of the spiral galaxies (e.g. sizes of bulge, the tightness with which the spiral arms are wound)? What are the differences between the bulge component and the disk component of a spiral galaxy?

(4) What are the main differences between elliptical galaxies and spiral galaxies? Which dominate the number of small galaxies in the whole universe? Which dominate the number of massive galaxies? Which are more popular in loose groups and which are often seen in dense clusters?

2. (Understanding the cosmic expansion) There are two points in the two dimensional plane, as showed in Fig.2. There are two kinds of distance, one is the *grid distance* and the other one is the *physical distance*. The grid distance is measured in units of the grid size, while the physical distance is the physical length of one grid multiplied by the grid distance. For example, the distance between point A and point B is $\Delta l = \sqrt{\Delta x^2 + \Delta y^2} = \sqrt{3^2 + 4^2} = 5$. If the physical length of the side of the grid is $a = 10$m, then the physical distance is $\Delta L = a \times \Delta l = 50$m.

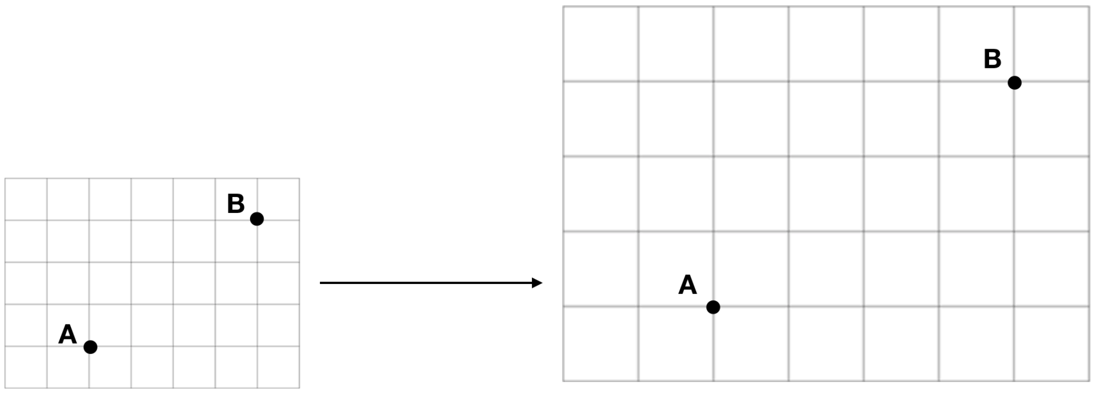

Figure 2: Expanding grid.

(1) If the grid is expanding, i.e. the physical distance of the grid is growing with a velocity of $da/dt = 1m/s$, and the relative positions of the points on the grid move with the expansion, what is the physical distance between point A and point B after 10s? ($a_{\mathrm{t}=0} = 10m$)

(2) The physical picture of the expansion of our Universe is exactly the same as the above question but with some fancy words. The *grid distance* above is actually called *co-moving distance* since all the objects move along with the cosmic expansion. The length of the side of the grid is called the scale factor that describe the conversion from the co-moving distance to the physical distance. The expansion rate, i.e. da/dt, is governed by the matter/energy content of our Universe though Friedman equation, which can be derived from General Relativity:

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G\rho}{3} \tag{1}$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p) \tag{2}$$

where $\dot{a}$ means da/dt, G is the gravitational constant, ρ is the matter density and p is the pressure. Suppose that $p = w\rho$, where w is a constant, could you solve this equation to get $a = a(t)$? (Hint: You may assume $a = a_0 t^n$ and get the index n from the equation).

(3) The observation tells us that our Universe is under accelerating expansion now, which value of w to choose can make the expansion of the Universe accelerating?

3. (Measure the Distance) Distance measurement is one of the most important tasks in modern astronomy. A variety of methods, which can be applied at different distances, form a chain of methods where the next method depends on the link between it and the previous one.

(1) Give a simple summary of the methods of distance measurements, from the one that can be applied in our solar system to the one that could reach to the boundary of the observable universe.

(2) What do we mean by standard candles? How are they calibrated? Explain how we can use the standard candles to measure the distances.

(3) Why are Cepheid variable stars so important? How can we use Cepheid variable stars to measure distances? What great achievements did Hubble made by using the Cepheid variable stars?

(4) (Cepheids in M100) Scientists using the Hubble Space Telescope have observed Cepheids in the galaxy M100. Here are the actual data for three Cepheids in M100:

- Cepheid 1: luminosity $= 3.9 \times 10^{30}$watts, brightness $= 9.3 \times 10^{-19}$ watt/m^2 .
- Cepheid 2: luminosity $= 1.2 \times 10^{30}$watts, brightness $= 3.8 \times 10^{-19}$ watt/m^2.
- Cepheid 3: luminosity $= 2.5 \times 10^{30}$watts, brightness $= 8.7 \times 10^{-19}$ watt/m^2.

Compute the distance to M100 with data from each of the three Cepheids. Do all the three distance estimates agree with each other? Based on your results, estimate the uncertainty in the distance you obtained.

(5) Why are white dwarf supernovae so useful, even though they are quite rare. Explain the basic idea that why we can use them as a standard candle?

(6) What is Hubble's Law? Draw a simple sketch to describe how our universe expands. What is Doppler redshift? What is cosmological redshift? What are the connections and differences between these two types of redshift? How can Hubble's Law be used to measure distances?

(7) (Distances From Hubble's Law) Imagine that you have obtained the spectra of several galaxies and have measured the redshift of each galaxy to determine its receding speed away from us. Here are your results:

- Galaxy 1: Receding speed is 15000 km/s.
- Galaxy 2: Receding speed is 20000 km/s.
- Galaxy 3: Receding speed is 25000 km/s.

Estimate the distance to each galaxy from Hubble's law assuming $H_0 = 70$ km/s/Mpc.

(8) Suppose that our universe expands at a constant rate (i.e. the increase of physical length per unit time is constant over cosmic time). Use what you have known about the Hubble constant to estimate the age of the universe.

4. (Galaxy Evolution) Galaxies are the islands of stars. Study of galaxy evolution provide great way to exam almost all the physical laws, to discover new physical phenomena, and to understand how our universe evolves.

(1) Give a general description about how a isolated galaxy forms (e.g. the initial condition, the collapse of gas, the star formation, and the origin of heavy elements). What are the differences between the halo stars and the disk stars and what are the differences in their formation processes?

(2) How does an elliptical galaxy form? (What initial condition can produce an elliptical galaxy? What processes can result in an elliptical galaxy?) Why do ellipticals have little cool gas and young stars?

(3) What role does the collision/merger of galaxies play in galaxy formation? What are the possible relations between collisions, formation of elliptical galaxies, star bursts and formation of super massive black holes?

(4) What are the characteristics of quasars? What is the possible energy source of an AGN? Which observational evidences show that the size of an AGN is small? Why can an AGN spectrum have broad wavelength range? What is the reason for the the existences of jets?

(5) (Your Last Hurrah) Suppose you fell into an accretion disk that swept you into a supermassive black hole. On your way down, the disk radiates 10% of your mass-energy, $E = mc^2$. What is your mass in kilograms? Calculate how much radiative energy will be produced by the accretion disk as a result of your fall into the black hole. Calculate approximately how long a 100-watt light bulb would have to burn to radiate this same amount of energy.