TUTORIAL 6

Class Assignment

1 All about Hubble

1.1 The Hubble classification of galaxies

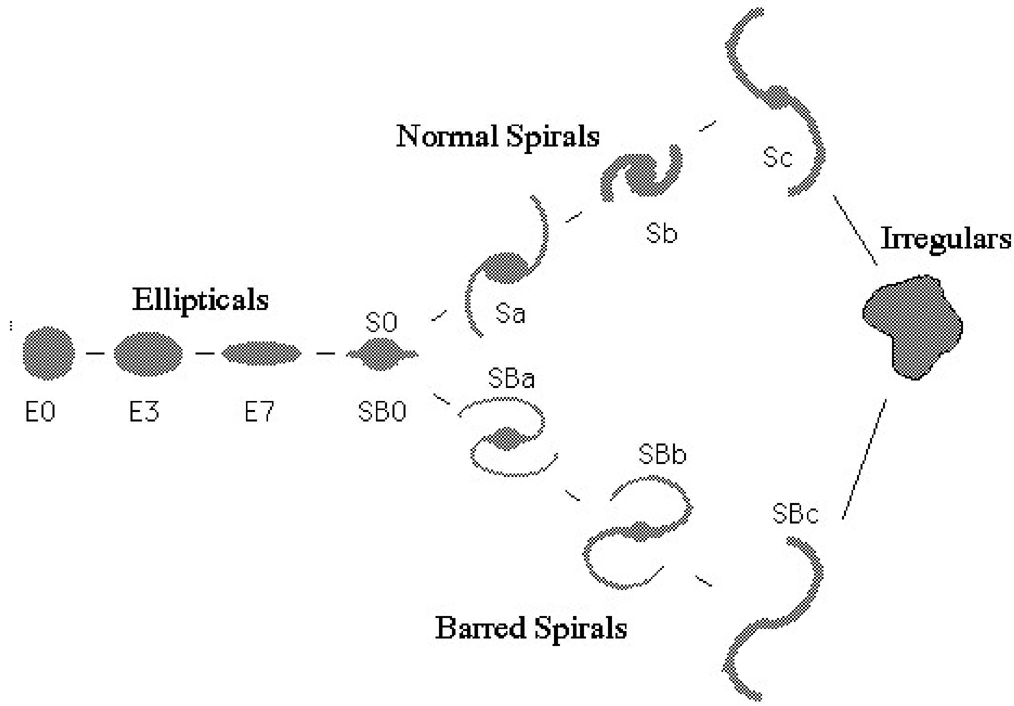

Figure 1: Hubble's Tuning Fork

The Hubble classification of galaxies, also referred to as the tuning fork diagram because of its shape, classifies galaxies into three main categories:

1. Elliptical galaxies
2. Spiral galaxies: Normal and Barred
3. Irregular galaxies

Edwin Hubble originally identified an evolutionary sequence for the galaxies (from early-type to late-type) as one moved from left to right across the diagram. Although this is now known to be a false interpretation, the terms early-type and late-type are still used regularly by astronomers in the manner described below, and when discussing broad galaxy types. The Hubble tuning fork diagram is illustrated in Figure 1.

Elliptical Galaxies
An elliptical galaxy shows no spiral structure and can vary from almost round (what Hubble called E0) to almost cigar shaped (called E7). This classification is based on our perspective from Earth and not on the actual shape.

Spiral Galaxies
As their name implies, spiral galaxies have outstretched, curving arms suggestive of a whirlpool or pinwheel. Hubble distinguished different sub-classes according to the tightness of the arms and the size of the nucleus. He called these Sa, Sb, and Sc. In terms of the arms, Sa is the tightest wound while Sc is the most open. In terms of the nucleus, Sa has the largest nucleus while Sc has the smallest. The galaxies that appear to have a spiral disc but no visible arms are classified as S0 galaxies.

Barred Spirals
Barred spirals show the same spiral structure as normal spirals, and also a prominent bar through the nucleus. The spiral arms emerge from the end of the bar. The sub-classifications are the same as for normal spirals.

Irregulars
Certain galaxies lack either an obvious spiral structure or nuclear bulge, appearing instead as a random collection of stars with no obvious order. They are distinguished from ellipticals by their lack of symmetry.

1.2 Hubble's Law

When the spectrum of distant galaxies is analyzed, we observe several absorption and emission lines. These lines appear to be shifted towards longer wavelengths from their original positions (red-shift). This shift occurs due to the motion of galaxies. By measuring the amount of shift of these spectral lines, we can derive the speed with which the galaxies move away from us. In 1929, Edwin Hubble measured the velocities of the near-by galaxies. By plotting the distances to the galaxies against their recessional velocities, he found that the velocity with which the galaxy recedes from us is proportional to its distance. This means that a distant galaxy will appear to recede faster than a near-by galaxy. This is known as Hubble's Law. This recession of galaxies can be seen in all directions. Hubble's law thus tells us that the universe is expanding.
It is given by the formula

$$v = H_0 \times D \tag{1}$$

Where v is the recessional velocity in km/s, D is the distance in Mpc and H_0 is the Hubble constant in $kms^{-1}Mpc^{-1}$. We shall use $H_0 = 70\ kms^{-1}Mpc^{-1}$ for our calculations.

Q1. You will be shown some galaxies on the screen. Observe carefully and classify them based on their morphologies using the Hubble classification given in Figure 1. Fill in Table 1. You are also given the distances to these galaxies. Use Hubble's law to calculate the recessional velocities.

Galaxy	Type	Your Reason	Distance (Mpc)	Velocity
A			17.17	
B			7.1	
C			10.73	
D			0.05	
E			3.52	
F			19.9	
G			16.4	
H			9.54	

Table 1

2 Rotation Curve of Galaxies

A galaxy is a gravitationally bound system of stars, interstellar gas, dust and stellar remnants. These different components are rotating around the galaxy's center. This was deduced by studying the Doppler shift in spectral lines from gas or stars in different parts of a galaxy. This Doppler shift can be used to infer the orbital velocity of the gas or stars. A plot of the orbital velocity against the radial distance from the galaxy's center is called the **Rotation Curve** of the galaxy. Most of the mass in a galaxy is concentrated at its center. Thus, the stars close to the center have very high velocities of rotation. As you go away from the center, the matter visible to us decreases. Thus, one expects that the velocity of the stars would decrease gradually. This is illustrated in Figure 2.

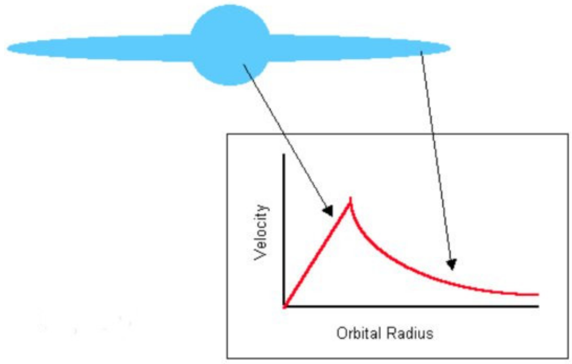

Figure 2: Expected rotation curve of a galaxy

Q2a. Go to: astro.unl.edu/nativeapps/ and install the ClassAction - v.3 executable. Start the program, select the 'Animations' tab, go to page 4 and click 'Milky Way Rotational Velocity'. Here you will see the rotation curve of the Milky way. A box inside the plot calculates the mass of the galaxy inside a certain radius. Drag the dot on the red curve to different radial distances. What can you say about the rotation curve of the Milky Way as compared to the one shown in Figure 2 As you drag the dot to large radial distances, how does the value of enclosed mass change?

In the above exercise, you have seen that the rotation curve of the Milky way is very different from the one shown in Figure 2. The calculated mass also increases as you go to larger radial distances. This indicates that there is some matter which is not visible but does affect the orbital motion and speed of the stars in the galaxy. Let us see how much of this invisible or **Dark Matter** is contained in a spiral galaxy.

Q2b. Go to: wittman.physics.ucdavis.edu/Animations/RotationCurve/GalacticRotation.html

Click on the image to start the animation. Vary the mass of the different components given so that you can recreate the rotation curve. Once you have recreated the rotation curve, write down the mass of all the different components. What can you say about the dark matter content in a galaxy?

3 Multi-wavelength Astronomy

During the course of the lectures and tutorials, you may have grasped the importance of imaging celestial objects at different wavelengths. Every domain of the electromagnetic spectrum tells us something about these objects which otherwise would have remained unknown to us. Refer to Figure 3. The temperature of an object determines the type of electromagnetic radiation it emits, and hence different aspects of astronomy can be probed at different wavelengths.

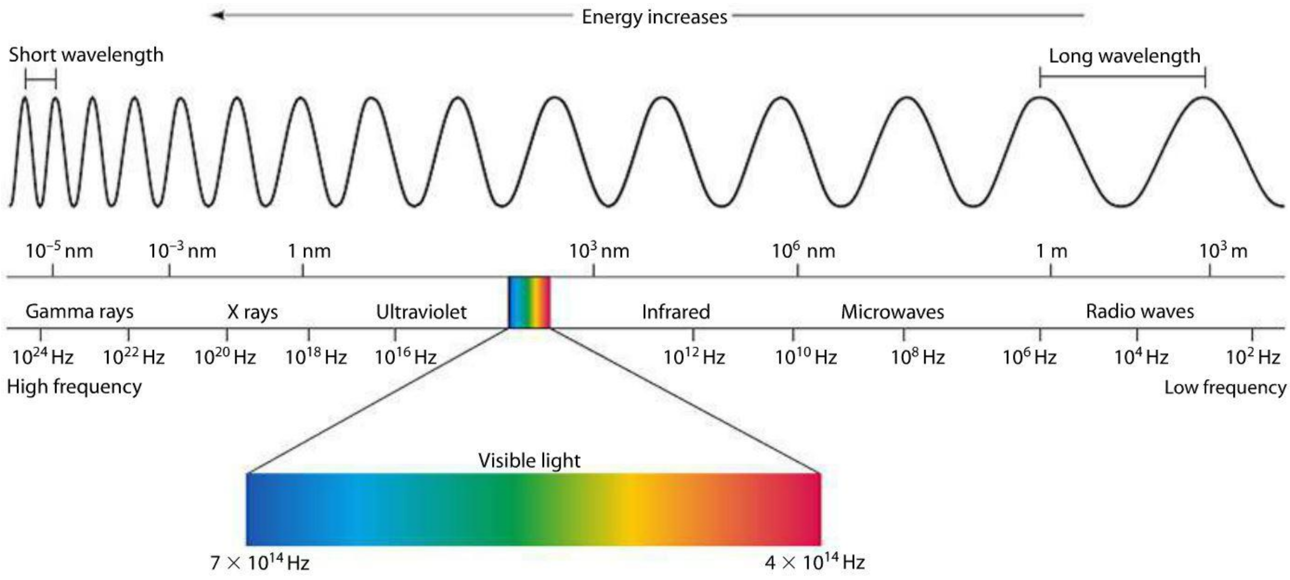

Figure 3: Electromagnetic Spectrum

1. Radio:
There are two types of radio emission that are significant:
1) Emission line of Hydrogen (HI line): The neutral hydrogen atom emits a photon at 21cm wavelength due to the hyperfine transitions in the atom. This radiation penetrates the dust clouds and gives us a more complete map of the hydrogen present in galaxies.
2) Radio continuum emission: This consists of continuous emission from a source due to its temperature (thermal continuum) or due to other physical processes such as presence of magnetic fields, collisions etc. (free-free or bremsstrahlung emission).

2. Infrared:
Parts of the Universe that remain obscured by dust in the optical wavelengths become visible or transparent at the infra-red wavelengths. Objects such as star-forming regions, brown dwarfs, planets and infra-red galaxies are studied using space-based infra-red telescopes.

3. Optical:
Optical or visible light astronomy is the oldest branch of astronomy. Many celestial objects have been studied in the past with the help of the naked eye and subsequently with the help of optical telescopes. Much of the information on our solar system, the Milky way and other galaxies has been acquired with the help of optical astronomy. In this band, we mainly observe nearby objects, stars in galaxies, dust lanes, distant galaxies etc.

4. UV:
At ultraviolet wavelengths, most stars fade from view because they are too cool to emit such high energy radiation. But very young massive stars, some very old stars, bright nebulae, white dwarfs stars,

active galaxies and quasars shine brightly in the ultraviolet. Light from this part of the spectrum also gives astronomers information about the chemical composition, densities, and temperatures of interstellar gas and dust. Discoveries have included the existence of a hot gaseous halo surrounding our own galaxy.

5. X- ray:
X-rays are emitted by highly energetic sources such as compact objects and supernovae. X-ray emission is also seen in the intra-cluster medium around galaxies in clusters.

On the screen, you will be shown Galaxy A, B and C imaged at different wavelengths.

Q3a. Observe these images for each galaxy carefully. Write about the importance of imaging at these different wavelengths, the physical processes that cause the emission at the wavelengths mentioned and what can be observed in these images. You can use space given below to write your answers.

Q3b. For A ,B and C, can you guess the Hubble type?