CHAPTER 2

Literature Review

2.1 Basics in Astronomical Observation

2.1.1 Astronomical Imaging Data

In astronomy, electromagnetic waves are the only data that we can retrieve from the celestial objects. To study these objects, scientific imaging data have to be taken by using a telescope and then generally are stored in Flexible Image Transport System (FITS) format with the image header information (RA, DEC, exposure time, etc). The digital image contains a set of the smallest addressable element called "PIXEL". Each pixel is capable to store the light intensity by 16-bit or 65,535 monochrome level.

Figure 2.1: Image of the NGC 4076 in B band with 16-bit monochrome level.

2.1.2 Filter

Stellar sources or celestial objects can produce blackbody radiation. The emitted thermal electromagnetic radiation can be in different wavelengths. Each range of wavelength can provide different astronomical information. In general, astrophysicists use the scientific filter to allow certain range of wavelengths to pass through the telescope, significantly increasing the signal in the wanted wavelength while blocking the lower and above bandpass of light. The most common scientific filter used in astronomy is the Johnson-Cousins filter system containing the UBVRI-filters. In this study, I use the B-, V- and R_C broadband filters, and Red-continuum and [SII] narrowband filters shown in Figure 2.2.

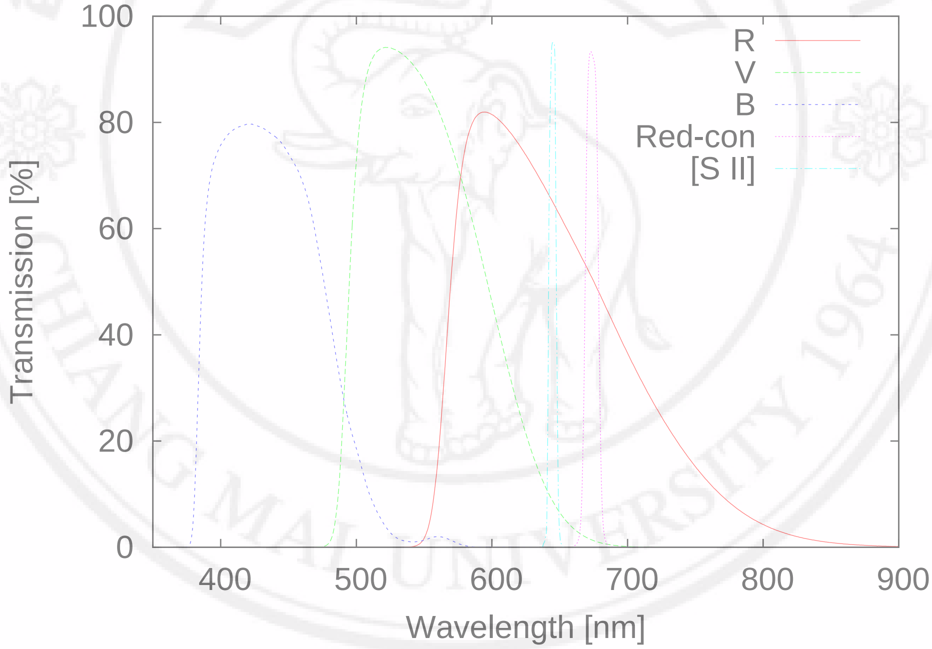

Figure 2.2: Transmission of B-, V-, R_C-, Red-continuum and [SII] filters.

2.1.3 Magnitude

Magnitude is the logarithmic scale for determining a brightness of the sky objects. In astronomy, There are two different kinds of definitions of magnitude, apparent magnitude and absolute magnitude.

Apparent Magnitude

In 1856, Norman R. Pogson observed a bright star with naked eyes and found that the brightest star is 100 times brighter than the dimmest star with six levels of magnitude. Thus, each level is $\sqrt[5]{100} \approx 2.512$ times. The apparent magnitude can be calculated by using Eq.2.1.

$$m_1 - m_2 \equiv -2.5 \log \frac{F_1}{F_2} \quad , \tag{2.1}$$

where

m_1, m_2 is the apparent magnitude of star 1 and star 2,

F_1, F_2 is the flux density of star 1 and star 2, respectively.

Absolute Magnitude

The apparent magnitude, which is used to measure brightness, does not represent the luminosity of the sky object. On the other hand, the absolute magnitude is the measurement of an object's luminosity at a distance of 10 parsecs. The absolute magnitude can be calculated by using Eq. 2.2.

$$M = m - 5 \log(r) + 5 \quad , \tag{2.2}$$

where

m is the apparent magnitude,

M is the absolute magnitude, and

r is the distance from earth to the sky object in unit of pc.

2.1.4 Color Index

In astronomy, the color index is the parameter used to represent the color of a sky object. It also indicates the surface temperature of the object. The color index can be determined by the difference between two bandpass magnitude (eg. $B-V$, $B-R$ or $V-R$). The smaller the color index, the bluer the object is. For comparison, The bluish Vega has a color index $B-V$ of 0.00 while the color index $B-V$ for yellowish Sun is 0.65.

2.1.5 Stellar Classification

There are numerous stars that exist in the universe. The classification of stars makes it easier to study their physical and chemical characteristics. Astronomers use spectral discrimination to classify the type of the stars. The Morgan-Keenan System is widely used, which is divided into seven types of stars represented by the English alphabets: "O", "B", "A", "F", "G", "K", and "M". Each can be distinguished by color, surface temperature, size and chemical component. Type "O" star is the most massive and the hottest star, whereas the other types are smaller and cooler. The classification image is shown in Figure 2.3.

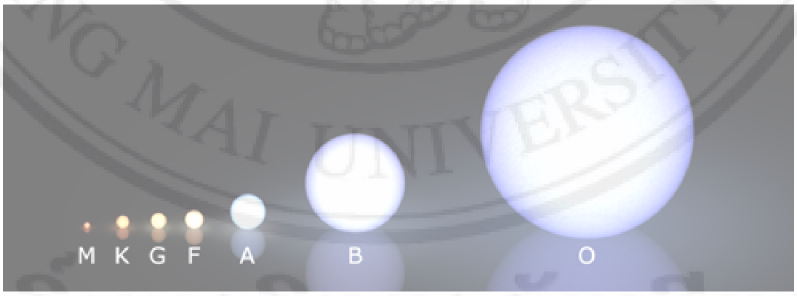

Figure 2.3: The classification of the star type along Morgan-Keenan system.
Source: http://en.wikipedia.org/wiki/File:Morgan-Keenan_ spectral_ classification.png

2.2 Galaxies and Group of Galaxies

A galaxy is a group of stars, gas, dust and dark matter bounded by the gravity of a massive black hole at the center. Unlike a star, a nearby galaxy is an extended object that cannot be easily observed by a small- to medium-sized telescopes. Thus, there are numerous observed galaxies with different shapes and sizes if they can be observed with sufficiently large telescope.

A galaxy group is a group of galaxies located in a small area of the sky. Typically, it contains fewer than fifty galaxies within a diameter of one or two megaparsecs. The Milky Way itself is a member of the galaxy group called "Local Group".

2.3 Galaxy Morphological Classification

In astronomy, the classification of a galaxy depends on their visual appearance. The widely used system, nowadays, is the Hubble sequence proposed by Edwin Hubble. In 1926, the astronomer named Edwin Hubble classified the galaxies into three main types: elliptical galaxies (E-), spiral galaxies (S-), and lenticular galaxies (S0) while the unclassified galaxies are called "Irregular Galaxies". The image of the Hubble sequence is shown on Figure 2.4.

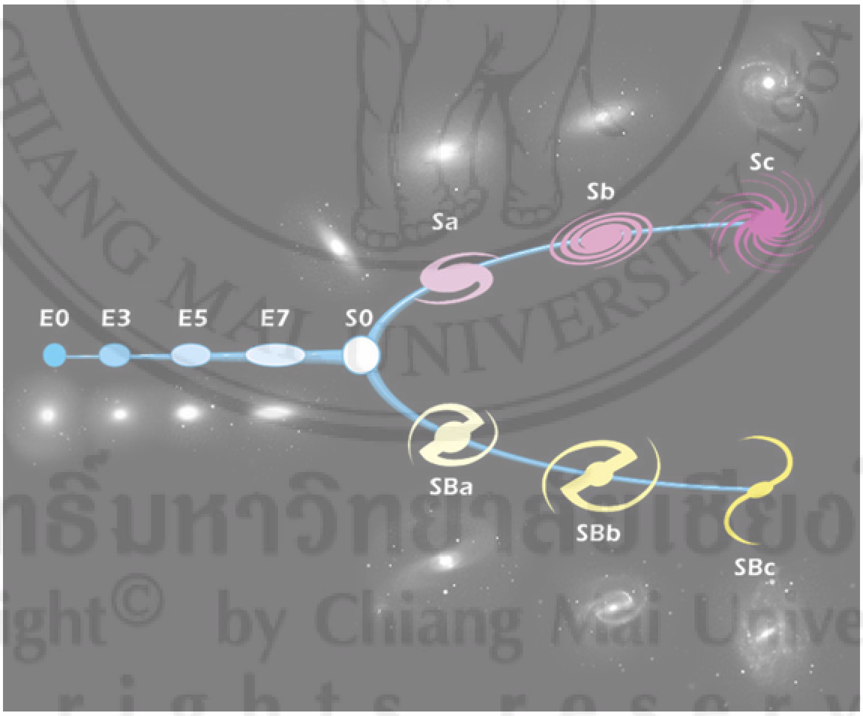

Figure 2.4: Edwin Hubble's classification scheme of the elliptical galaxies (Left) and the spiral galaxies (right)
Source: http://en.wikipedia.org/wiki/File:HubbleTuningFork.jpg

2.3.1 Elliptical Galaxies

An elliptical galaxy is ellipsoidal in shape with gradual brightness, i.e., very bright at the center and slightly faint at the edge, galaxy. Moreover, elliptical galaxies can be divided into seven levels by the ratio of the major axis to the minor axis of their isophotes using Eq. 2.3.

$$n = 10 \times (1 - \frac{b}{a}) \qquad , \tag{2.3}$$

where

n is the elliptical level number of galaxies (integer 0 to 7),

a is the major axis of a galaxy , and

b is the minor axis of a galaxy.

2.3.2 Spiral Galaxies

Spiral galaxies are galaxies containing spiral-shaped arms, a flat rotating disk of star and gas, and a galactic bulge, the abundance and dense concentration of stars and gas at the center of a galaxy. Spiral galaxies can be classified into two types: the normal spiral galaxies (S-) and the spiral bar galaxies (SB-) classified by a shape of the galaxy bulge. Furthermore, a spiral galaxy can also be classified by their arms (-a, -b, -c), i.e., Sa or SBa for tightly and wrapped arms, and Sc or SBc for loose and unwrapped arms.

2.3.3 Lenticular Galaxies

A lenticular galaxy has galaxy shape that sits somewhere between an elliptical galaxy and a spiral galaxy in the Hubble's classification diagram. It has a gradual brightness like the elliptical and a galactic bulge like the spiral. Lenticular galaxies are denoted only by S0.

2.4 Interactions

Astrophysicists focus on studying the following interactions that occur within the cluster of galaxies, the tidal interactions (galaxy-galaxy and galaxy-cluster) for studying of their gravitational correlation, ram pressure and viscous stripping to study the hydro-dynamic interactions between the galaxy interstellar medium.

2.4.1 Tidal Interaction

Tidal interactions act on gas, dust and stars within a pair of galaxies. If the tidal force is sufficiently strong, their gas could be consumed to form young massive stars and might change the morphology of the galaxy. The perturbation of galaxy-galaxy parameter can be calculated using Eq. 2.4 [Byrd and Valtonen, 1990].

$$P_{gg} = (\frac{M_{comp}}{M_{gal}})(\frac{d}{r_{gal}})^{-3} \quad , \tag{2.4}$$

where

M_{comp} is the companion mass,

M_{gal} is the mass of a galaxy,

r_{gal} is the visible disk radius of a galaxy, and

d is the distance between the two galaxies.

If the mass of the galaxy cluster is greater than 10^{14} M_{sun}, the potential energy of the galaxy cluster can affect the galaxies to fall into the center of the cluster (Merritt, 1984). This interaction also perturbs the interstellar medium of galaxy members and may cause a morphological change. The perturbation of galaxy-galaxy cluster parameter can be calculated by using Eq. 2.5 [Byrd and Valtonen, 1990].

$$P_{gc} = (\frac{M_{cluster}}{M_{gal}})(\frac{R_{center}}{r_{gal}})^{-3} \quad , \tag{2.5}$$

where

$M_{cluster}$ is the galaxy cluster's mass, and

R_{center} is the distance between the galaxy and the cluster center.

2.4.2 Galaxy Harassment

Galaxy harassment is the process of a high velocity galaxy-galaxy close (~ 50 kpc) encounter causing the multiple collisions between galaxy components [Moore et al., 1996]. This interaction is one of the main causes for driving the galaxy's evolution. Unlike tidal interaction, galaxy harassment produces heat during the process, and also causes particles to increase velocity, losing their angular momentum, thus causing the interstellar medium to fall into the galaxy center.

2.4.3 Ram Pressure

Ram pressure is an interaction caused by galaxies moving through a hot dense intergalactic medium [Gunn and Gott, 1972]. If a galaxy with a velocity of ~ 1000 km.s^{-1} moves through the intergalactic medium that has a temperature of more than $\sim 10^7 - 10^8$ K and a density of more than $\sim 10^{-3} - 10^{-4}$ atoms.cm^{-3}, it could induce the ram pressure, enough to remove the interstellar medium from the galaxy and drive the interstellar medium into the disk under the condition:

$$\rho_{IGM} V_{gal}^2 > 2\pi G \Sigma_{star} \Sigma_{gas} \quad , \tag{2.6}$$

where

ρ_{IGM} is the density of the intergalactic medium,

V_{gal} is the galaxy's velocity,

G is the gravitational constant,

Σ_{star} is the stellar surface density, and

Σ_{gas} is the gas surface density.

The surface density can be calculated by

$$\Sigma_{star} = \frac{l_{ratio} L_H}{\pi(a_{optical}/2)^2} \quad , \tag{2.7}$$

where

l_{ratio} is the mass-to-light ratio,

L_H is the H-band luminosity, and

$a_{optical}$ is the optical semi-major axis of the galaxy

and

$$\Sigma_{gas} = \frac{M(HI) + M(H_2)}{\pi(a^2_{optical}/2a_{HI})^2} \quad , \tag{2.8}$$

where

$M(HI)$ is the estimate mass of HI region,

$M(H_2)$ is the estimate mass of molecular H_2 gas region, and

a_{HI} is the HI gas region diameter.

2.4.4 Viscous Stripping

Viscous stripping mechanism [Nulsen et al., 1982] could remove interstellar medium out of the galaxy. Consider a galaxy containing cold gas moving through a hot and low density intergalactic medium, the outer part of the galaxy undergoes a viscosity momentum transfer, causing the force to pull out the interstellar medium from the host galaxy. In the normal case (the flux is laminar), the rate of mass loss during the process can be calculated using Eq. 2.9.

$$M_{laminar} \approx \frac{F_{laminar}}{V_{gal}} = \frac{12}{Re} \pi r^2_{gal} \rho_{IGM} V_{gal} \quad , \tag{2.9}$$

where

$F_{laminar}$ is the drag force, and

Re is the Reynolds number.

The Reynolds number can be calculated by

$$Re = (2.8)(\frac{r_{gal}}{\lambda_{IGM}})(\frac{V_{gal}}{C_{IGM}}) < 30 \qquad , \tag{2.10}$$

where

C_{IGM} is the sound speed in the intergalactic medium, and

λ_{IGM} is the particle mean free path in intergalactic medium.

2.4.5 Thermal Evaporation

This mechanism could be significant when the temperature of the intergalactic medium is much higher than the interstellar medium. The heat will be transferred rapidly, causing an increase in velocity and kinetic energy of the interstellar medium. Therefore, the interstellar medium rises beyond the gravitational field, letting the gas escape [Cowie and Songaila, 1977]. The mass loss during this process can be calculated using Eq. 2.11.

$$M_{evaporation} = 4\pi r_{gal}^2 \rho_{IGM} C_{IGM} \phi_s f(\sigma_0) \qquad , \tag{2.11}$$

Based on a research by Nulsen et al. [1982], some of the parameters can be determined as $\phi_s = 1,\ \sigma_0 = 1.84\frac{\lambda_{IGM}}{r_{gal}\phi_s},\ and\ f(\sigma_0) = 2\sigma_0$ for $\sigma_0 \leqslant 1$. The Eq. 2.11 can then be rewritten as

$$M_{evaporation} = 14.7\pi r_{gal} \rho_{IGM} C_{IGM} \lambda_{IGM} \qquad , \tag{2.12}$$

2.4.6 Starvation Mechanism

This mechanism can explain how a spiral type galaxy becomes a lenticular type galaxy. Consider that the galaxy itself needs gas to produce stars. For a long time, the gas is insufficient to produce star formation, thus the rate of star formation decreases and becomes stable. Afterwards, the spiral arms dissolve and become linear [Larson et al., 1980].