

# Introduction to Observational Astronomy - PHY2029

## Assignment 1

Thomas Mills

Student No.: 210055795

### Question 1:

#### Part a:

i:

$2.5 \times 10^{17} \text{ Hz}$  is situated in the X-ray part of the EM spectrum.

ii:

$8.0 \times 10^{14} \text{ Hz}$  is situated in the ultraviolet part of the spectrum.

iii:

$1.4 \times 10^9 \text{ Hz}$  is situated in the microwave part of the spectrum.

#### Part b:

i:

$$E = h\nu$$
$$E = (6.626 \times 10^{-34})(2.5 \times 10^{17}) = 1.6565 \times 10^{-16} \text{ J}$$
$$E_{ev} = \frac{1.6565 \times 10^{-16}}{1.6022 \times 10^{-19}} = 1033.8909 \text{ eV}$$

ii:

$$E = h\nu$$
$$E = (6.626 \times 10^{-34})(8 \times 10^{14}) = 5.3008 \times 10^{-19} \text{ J}$$
$$E_{ev} = \frac{5.3008 \times 10^{-19}}{1.6022 \times 10^{-19}} = 3.30845088 \text{ eV}$$

iii:

$$E = h\nu$$
$$E = (6.626 \times 10^{-34})(1.4 \times 10^9) = 9.2764 \times 10^{-25} \text{ J}$$
$$E_{ev} = \frac{9.2764 \times 10^{-25}}{1.6022 \times 10^{-19}} = 5.78978904 \times 10^{-6} \text{ eV}$$

#### Part c:

i:

$$\nu = 2.49999999 \times 10^{17} \text{ Hz} - 2.50000001 \times 10^{17} \text{ Hz}$$

$$F = \int_{2.50000001 \times 10^{17}}^{2.49999999 \times 10^{17}} 1 d\nu = [\nu]_{2.50000001 \times 10^{17}}^{2.49999999 \times 10^{17}} = (2.50000001 \times 10^{17}) - (2.49999999 \times 10^{17})$$
$$= 2000000000 \text{ W m}^{-2} = 2 \times 10^9 \text{ W m}^{-2}$$

**ii:**

$$\nu = 7.99999 \times 10^{14} \text{ Hz} - 8.00001 \times 10^{14} \text{ Hz}$$

$$F = \int_{8.00001 \times 10^{14}}^{7.99999 \times 10^{14}} 1 d\nu = [\nu]_{8.00001 \times 10^{14}}^{7.99999 \times 10^{14}} = (8.00001 \times 10^{14}) - (7.99999 \times 10^{14}) \\ = 2000000000 \text{ W m}^{-2} = \mathbf{2 \times 10^9 \text{ W m}^{-2}}$$

**iii:**

$$\nu = 4 \times 10^8 \text{ Hz} - 2.4 \times 10^9 \text{ Hz}$$

$$F = \int_{4 \times 10^8}^{2.4 \times 10^9} 1 d\nu = [\nu]_{4 \times 10^8}^{2.4 \times 10^9} = (2.4 \times 10^9) - (4 \times 10^8) = 2000000000 \text{ W m}^{-2} \\ = \mathbf{2 \times 10^9 \text{ W m}^{-2}}$$

**Part d:**

**i:**

$$F = 2 \times 10^9 \text{ J s}^{-1} \text{ m}^{-2}$$

$$2 \times 10^9 \times 10 = 2 \times 10^{10} \text{ Joules every 10 seconds per meter}^2$$

$$1.6565 \times 10^{-16} \text{ J for every photon.}$$

$$\frac{2 \times 10^{10}}{1.6565 \times 10^{-16}} = \mathbf{1.207364926 \times 10^{26} \text{ m}^{-2}}$$

**ii:**

$$F = 2 \times 10^9 \text{ J s}^{-1} \text{ m}^{-2}$$

$$2 \times 10^9 \times 10 = 2 \times 10^{10} \text{ Joules every 10 seconds per meter}^2$$

$$5.3008 \times 10^{-19} \text{ J for every photon.}$$

$$\frac{2 \times 10^{10}}{5.3008 \times 10^{-19}} = \mathbf{3.773015394 \times 10^{28} \text{ m}^{-2}}$$

**iii:**

$$F = 2 \times 10^9 \text{ J s}^{-1} \text{ m}^{-2}$$

$$2 \times 10^9 \times 10 = 2 \times 10^{10} \text{ Joules every 10 seconds per meter}^2$$

$$9.2764 \times 10^{-25} \text{ J for every photon.}$$

$$\frac{2 \times 10^{10}}{9.2764 \times 10^{-25}} = \mathbf{2.256008797 \times 10^{34} \text{ m}^{-2}}$$

It becomes important in certain frequency regimes where the energy of individual photons is significant compared to the energy of the system as a whole. In these regimes, the quantum properties of radiation can manifest themselves in various ways such as the photoelectric effect, Compton scattering and pair production. Understanding the quantum nature of light is fundamental when dealing with UV, X-Ray and Gamma frequencies where the energy of the individual photons is large.

**Part e:**

$$s = \frac{L}{4\pi r^2}$$

$$s_{\text{units}} = \frac{W}{m^2} = \frac{\frac{J}{s}}{m^2} = \frac{J}{sm^2} = \text{J s}^{-1} \text{ m}^{-2}, \quad \therefore \text{The units of } s \text{ are } \text{J s}^{-1} \text{ m}^{-2} \text{ or } \text{W m}^{-2}$$

$$\sigma = \frac{F}{\Omega}, \quad \Omega = \frac{A}{D^2} \approx \frac{\pi r^2}{D^2} \approx \frac{\pi \theta^2}{4}$$

$$\sigma = \frac{\int \frac{L_v}{4\pi D^2} dv}{\frac{\pi r^2}{D^2}} = \frac{\frac{L_v}{4\pi D^2}}{\frac{\pi r^2}{D^2}} = \frac{L_v}{4\pi^2 r^2} = \left(\frac{1}{\pi}\right) \frac{L_v}{4\pi r^2} = \frac{1}{\pi} s = \frac{s}{\pi}$$

$$\sigma = \left(\frac{1}{\pi}\right) \frac{L_v}{4\pi r^2}, \quad \therefore \text{brightness is independent of distance to source (D)}.$$

## **Question 2:**

### **Part a:**

a = 4830, Object ID = 1237648705114275972

b = 906, Object ID = 1237651538166415486

### **Part b:**

Absolute magnitude (M) is the apparent magnitude (m) a source would have if observed from a distance of 10pc (parsecs).

### **Part c:**

$$m - M = 5 \log_{10} \left( \frac{D_L}{10pc} \right)$$

#### **Galaxy A:**

$$m_r = 17.34858$$

$$D_L = 329.2316649228364 Mpc$$

$$M_r = m_r - 5 \log_{10} \left( \frac{D_L}{10pc} \right)$$

$$M_r = 17.34858 - 5 \log_{10} \left( \frac{329.2316649228364 \times 10^6 pc}{10pc} \right)$$

$$\textbf{\underline{Absolute Magnitude of Galaxy A: } } M_r = -20.23892799$$

#### **Galaxy B:**

$$m_r = 17.2862$$

$$D_L = 442.6228746364818 Mpc$$

$$M_r = m_r - 5 \log_{10} \left( \frac{D_L}{10pc} \right)$$

$$M_r = 17.2862 - 5 \log_{10} \left( \frac{442.6228746364818 \times 10^6 pc}{10 pc} \right)$$

**Absolute Magnitude of Galaxy B:  $M_r = -20.94336927$**

**Galaxy B is intrinsically brighter in the r-band than Galaxy A.**

$$M_{r,B} < M_{r,A} \therefore M_{r,B} \text{ is intrinsically brighter}$$

**Part d:**

$$colour = m_g - m_r$$

Higher g-r colour means redder. ( $\lambda_r > \lambda_g$ )

**Galaxy A:**

$$g = 18.14058$$

$$r = 17.34858$$

$$colour = 18.14058 - 17.34858 = \mathbf{0.792}$$

**Galaxy B:**

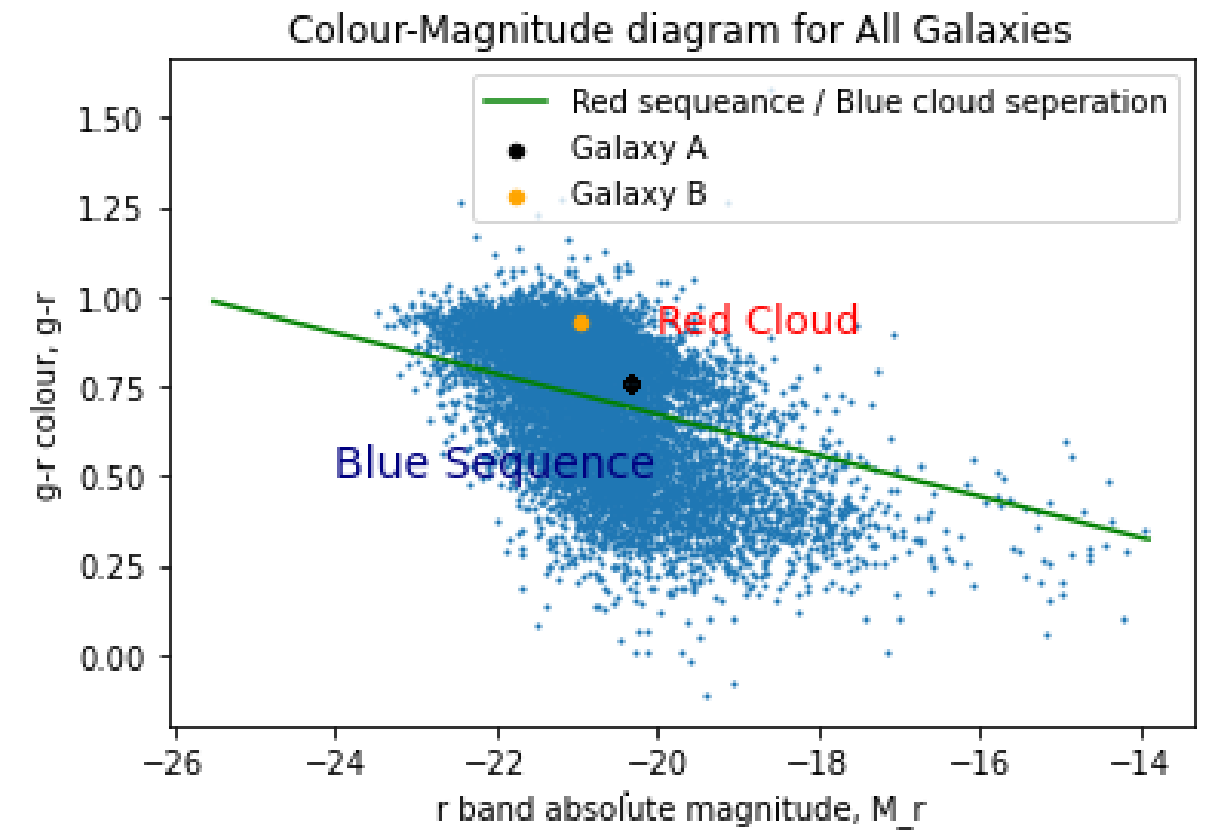
$$g = 18.21844$$

$$r = 17.2862$$

$$colour = 18.21844 - 17.2862 = \mathbf{0.93224}$$

$$colour_B > colour_A \therefore \text{galaxy B is redder}$$

### Part e:



### Part d:

The filter response curves for SDSS bands show that the g-band is centred around 475nm, while the z-band is centred around 925nm. Data for star temperature demonstrate that the peak wavelength of a star's spectrum is related to its temperature. Hotter stars emit more blue light and cooler stars emit more red light. Based on this, we can conclude that stars with a temperature range that corresponds to blue light (O, B, and A stars) could have their spectrum peak in the g-band. On the other hand, stars with a temperature range that corresponds to red light (K and M stars) could have their spectrum peak in the z-band.

The colours of galaxies can be used to infer something about the ages of the stellar populations inside galaxies. The colours of a galaxy depend on the combined light of its stars. Younger stars are generally bluer, while older stars are generally redder. Therefore, by analysing the colours of galaxy's, we can estimate the age of the stellar population within them. For example, a galaxy with a mainly blue colour would suggest a younger stellar population, whereas a mainly red colour would suggest an older stellar population. This information can provide insights into the formation and evolution of galaxies over time.

### **Question 3:**

#### **Part a:**

	Right Ascension (RA)	Declination (DEC)
Galaxy A	184.14566666666664°	0.4445555555555426°
Galaxy B	141.30974999999998°	59.41844444444445°

Galaxy A is in the Northern celestial hemisphere. DEC>0°

Galaxy B is in the Northern celestial hemisphere. DEC>0°

#### **Part b:**

##### **Galaxy A:**

$$RA = 184.14566666666664^\circ$$

$$\frac{184.14566666666664^\circ}{15} = 12.27637778 \text{ hours (as 1 hour} = 15^\circ)$$

$$\Rightarrow 12 \text{ hours} + 0.27637778 \text{ hours}$$

$$\Rightarrow 12 \text{ hours} + 16 \text{ minutes} + 0.5826668 \text{ minutes}$$

$$\Rightarrow 12 \text{ hours} + 16 \text{ minutes} + 34.960008 \text{ seconds}$$

$$\text{Galaxy A: RA} = 12:16:34.960008 \text{ or } (12^h 16^m 34.960008^s)$$

$$DEC = 0.4445555555555426^\circ$$

$$0.4445555555555426^\circ \times 60 = 26.67333333 \text{ arcminutes (as } 1^\circ = 60 \text{ arcminutes)}$$

$$\Rightarrow 0^\circ + 26' + 0.67333333''$$

$$\Rightarrow 0^\circ + 26' + 40.4''$$

$$\text{Galaxy A: DEC} = 0:26:40.4 \text{ or } (0^\circ 26' 40.4'')$$

##### **Galaxy B:**

$$RA = 141.30974999999998^\circ$$

$$\frac{141.30974999999998^\circ}{15} = 9.42065 \text{ hours (as 1 hour} = 15^\circ)$$

$$\Rightarrow 9 \text{ hours} + 0.42065 \text{ hours}$$

$$\Rightarrow 9 \text{ hours} + 25 \text{ minutes} + 14.34 \text{ seconds}$$

$$\text{Galaxy B: RA} = 09:25:14.34 \text{ or } (9^h 25^m 14.34^s)$$

$$DEC = 59.41844444444445^\circ$$

$$59.41844444444445^\circ = 59^\circ + 0.41844444444445 \text{ arcminutes}$$

$$\Rightarrow 59^\circ + 25' + 6.4''$$

**Galaxy B: DEC = +59:25:6.4 or (59° 25' 6.4'')**

**Part c:**

Angular separation of galaxy A and galaxy B.

$$\alpha = RA, \beta = DEC$$

$$A : (\alpha_A, \beta_A) \quad , \quad B : (\alpha_B, \beta_B)$$

$$\theta_{seperation} = \cos^{-1}[\sin(\beta_A) \sin(\beta_B) + \cos(\beta_A) \cos(\beta_B) \times \cos(\alpha_A - \alpha_B)]$$

$$\begin{aligned} \theta_{seperation} = \cos^{-1} & [\sin(0.4445555555555426^\circ) \sin(59.41844444444445^\circ) \\ & + \cos(0.4445555555555426^\circ) \cos(59.41844444444445^\circ) \\ & \times \cos(184.14566666666664^\circ - 141.30974999999998^\circ)] \end{aligned}$$

$$\theta_{seperation} = 67.6819734^\circ$$

**Part d:**

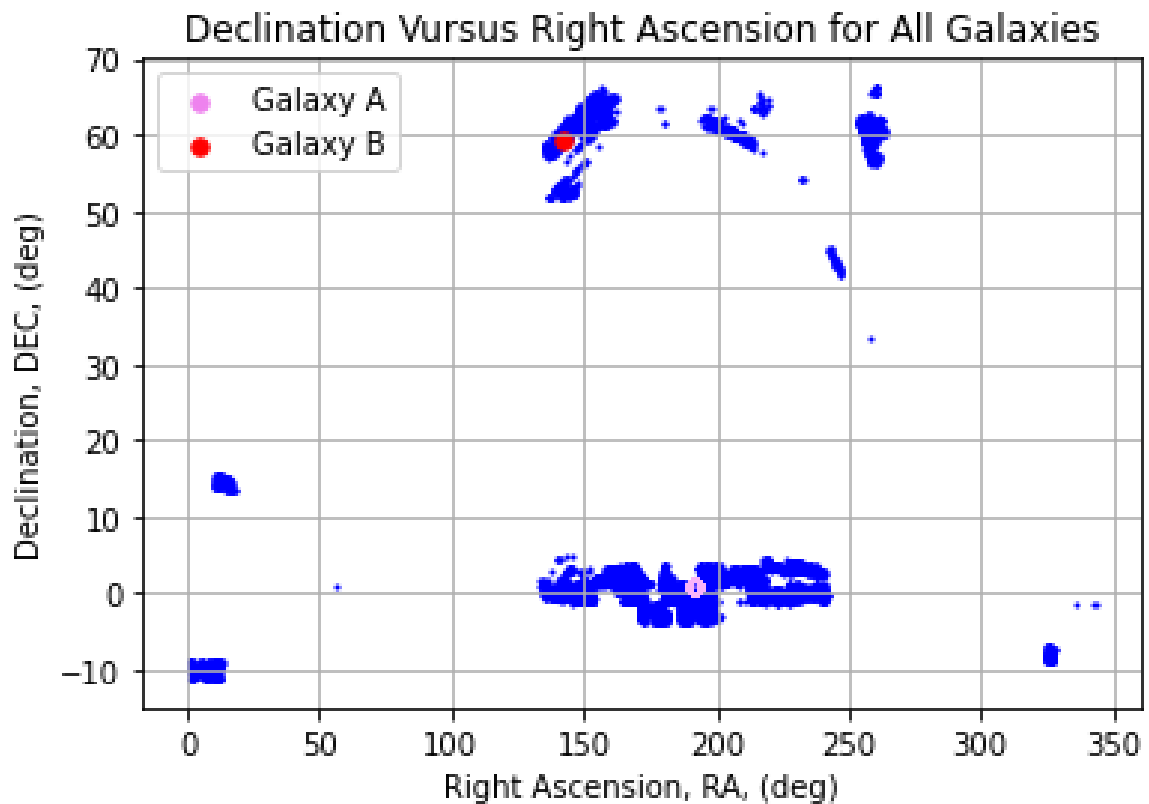


Figure 3.1: Plot of DEC versus RA for all of the galaxies in the table, which highlight the different patches of the sky covered by this SDSS data. On this diagram Galaxy A and Galaxy B are highlighted.

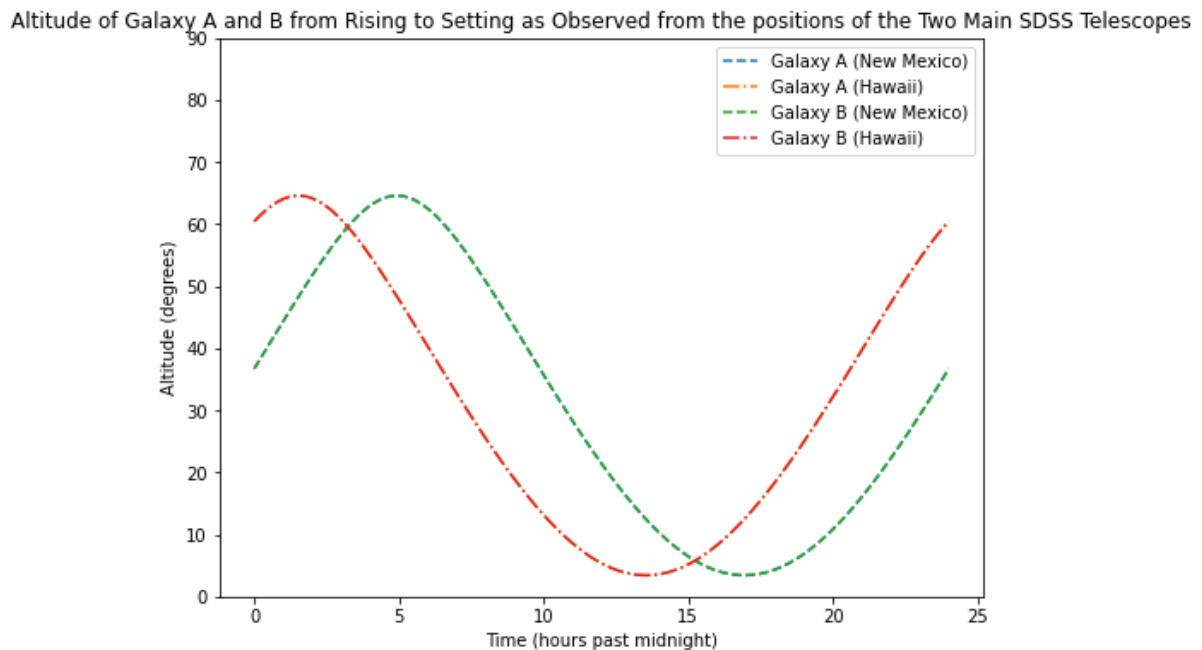


Figure 3.2: Plot how the altitude of these sources will vary from rising to setting as observed from the location of the telescope which made these observations. The SDSS has to main telescopes, one in New Mexico, another in Hawaii.

For galaxy A, (DEC = 0.4445), it will be visible at high altitudes for observers located close to the equator. As it moves from rising to setting, its altitude will increase until it reaches its maximum height above the horizon. After that, its altitude will decrease until it sets below the horizon. This path will be fairly flat and close to the horizon for observers located at high latitudes, such as those in New Mexico. For galaxy B, (DEC = 59.4184), it will appear higher in the sky for observers located in the northern hemisphere, and its altitude will increase as it moves from rising to its maximum height. After reaching its maximum height, its altitude will start to decrease until it sets below the horizon. For observers located in Hawaii, galaxy B will appear very high in the sky, while for those in New Mexico, it will appear lower in the sky.

The right ascension of a celestial source determines the time of day it is visible. Objects with a higher RA are visible earlier in the night and those with a lower RA are visible later in the night.

For observers in New Mexico, the best time to observe galaxy A would be around the autumnal equinox (~September 22), where it is visible in the early evening. For galaxy B, the best time to observe it would be around the summer solstice (~June 21), when it is visible for the longest time during the night.

For observers in Hawaii, galaxy B would be visible for a longer time during the night than for observers in New Mexico due to its higher altitude. The best time to observe it would be around the vernal equinox (~March 20) when it is visible in the early evening. Galaxy A would be visible for a shorter time during the night and at lower altitudes than for observers in New Mexico, so the best time to observe it would be during the winter months so it is visible in the early evening.

#### **Question 4:**

##### **Part a:**

*H $\alpha$  emission line = 656.56nm (in vacuum)*

$$\lambda_{observed} = z\lambda_{H\alpha} + \lambda_{H\alpha}$$

**Galaxy A:**

$$Z = 0.0728652$$

$$\text{Galaxy A: } \lambda_{observed} = 0.0728652 \times 656.46 + 656.46 = 704.2930892nm$$

**Galaxy B:**

$$Z = 0.09639389$$

$$\text{Galaxy B: } \lambda_{observed} = 0.09639389 \times 656.46 + 656.46 = 719.738733nm$$

##### **Part b:**

$$L_{em} = 4\pi D_L^2 F_{em}$$

$$\text{For } H\alpha: L_{H\alpha} = 4\pi D_L^2 F_{H\alpha}$$

**Galaxy A:**

$$F_{H\alpha} = 246.688 \times 10^{-17} \text{ ergs}^{-1} \text{ cm}^{-2}$$

$$D_L = 329.2316649228364 \text{ Mpc} = 1.01590276707846864 \times 10^{27} \text{ cm}$$

$$L_{H\alpha} = 4\pi(1.01590276707846864 \times 10^{27})^2 \times 246.688 \times 10^{-17}$$

$$L_{H\alpha} = 3.199353103 \times 10^{40} \text{ ergs}^{-1}$$

$$\text{Galaxy A: } L_{H\alpha} = 3.199353103 \times 10^{33} W$$

**Galaxy B:**

$$F_{H\alpha} = 63.60484 \times 10^{-17} \text{ ergs}^{-1} \text{ cm}^{-2}$$

$$D_L = 442.6228746364818 \text{ Mpc} = 1.3657914812407785 \times 10^{27} \text{ cm}$$

$$L_{H\alpha} = 4\pi(1.3657914812407785 \times 10^{27})^2 \times 63.60484 \times 10^{-17}$$

$$L_{H\alpha} = 1.490969734 \times 10^{40} \text{ ergs}^{-1}$$

$$\text{Galaxy B: } L_{H\alpha} = 1.490969734 \times 10^{33} W$$

**Part c:**

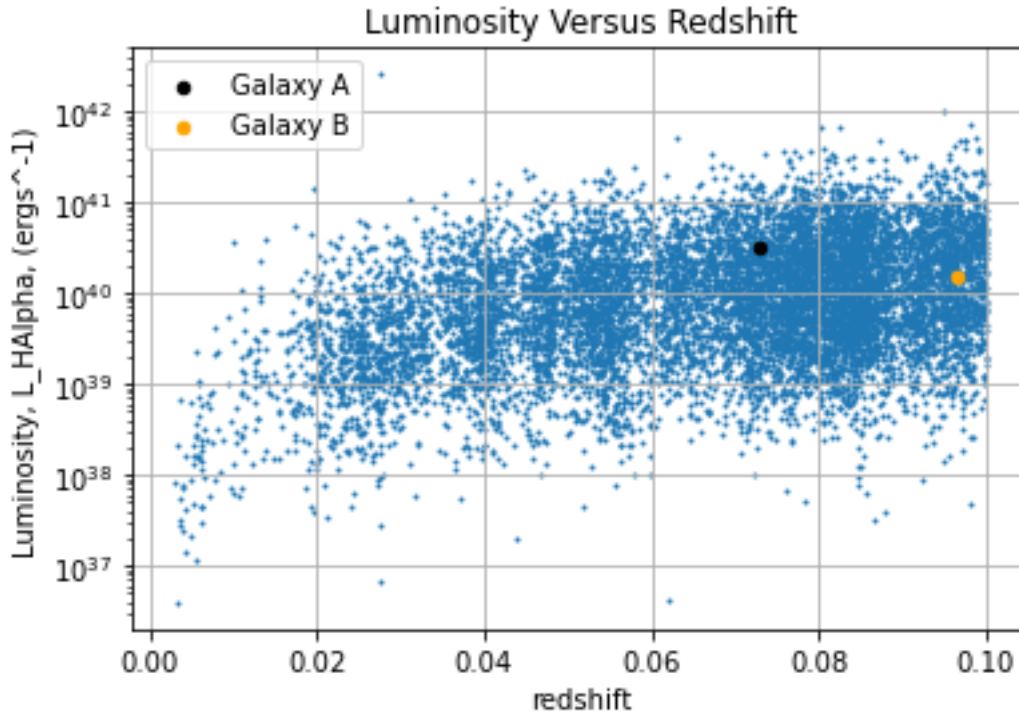


Figure 4.1: Plot of  $L_{H\alpha}$  versus redshift for the all the galaxies in the table. Galaxy A and Galaxy B are highlighted.

Galaxies that cannot be detected in  $H\alpha$  emission due to the flux limit will not appear in the table. Therefore, the distribution of data points of the Luminosity versus redshift diagram will not be representative of the entire population of galaxies. It will only include those galaxies that emit enough  $H\alpha$  flux to be detected.

### **Part e:**

The presence of an AGN (Active Galactic Nucleus) in a galaxy can complicate the use of galaxy colours to infer something about stellar populations in several ways.

1. AGN's are defined by a bright central source of radiation that can contribute substantially to the galaxy's total luminosity. This can lead to an amplification of the actual luminosity of the galaxy and can camouflage the true radiation contribution. As a result, the measured colours of the galaxy may not reflect the actual colours of the galactic population, making it difficult to infer properties of the galaxy.
2. AGN's radiation can also be across a wide range of wavelengths. This can cause contamination of the observed colours of the galaxy. The AGN emission can mimic the colours of young stars, leading to confusion in the interpretation of the observed colours and the inferred galactic population properties.

In the standard model of AGN's, the type of AGN that will be most affected is a Type 1 AGN. Type 1 AGN's are defined by broad emission lines in the optical spectra, which come from gas clouds that are close to the central black hole and are ionized by the high radiation from the accretion disk of the black hole. The broad emission lines can contaminate the observed colours of the galaxy in the bands, making it difficult to separate the contribution of the AGN from the underlying galactic population. This can make it difficult to get accurate data on the properties of the galactic population.