Astronomy 218 Problem Set 1

Emily Ramey

16 September 2019

1. Morphological Classification

   If I had to design a morphological galaxy classification system, I would probably attempt to make it easier to tell the properties of a galaxy at a glance. Galaxies would have a letter denoting their shape/type and numbers for mass, color, metallicity, etc. (in that order). If any of these quantities were not known, the letter/number would be represented with a hyphen.

   For shape, galaxies would have an 'S' for spiral, an 'E' for elliptical, an 'L', for lenticular, and an 'I' for irregular. Mass would be denoted on a sliding scale from 0-9. The intervals would be spaced so as to cover the majority of galaxies (say, to 3σ), with the tail-ends of the distribution included in the 0 and 9 categories. The color and metallicity would also be denoted on a 0-9 scale in much the same way, with the reddest color and highest metallicity at 9.

   Some examples of galactic classifications:
   - S325: A spiral galaxy with mass 3, blue color, and metallicity 5.
   - E79-: An elliptical galaxy with mass 7, a very red color, and an unknown metallicity.
   - I-1-: An irregular galaxy with unknown mass, very blue color, and unknown metallicity.

2. Galaxy Correlations in the SDSS

   (a) Plot the relation between gas-phase metallicity and stellar mass for galaxies in the SDSS and exclude the galaxies from which the relevant properties could not be measured. What physical processes could be responsible for the observed trend?

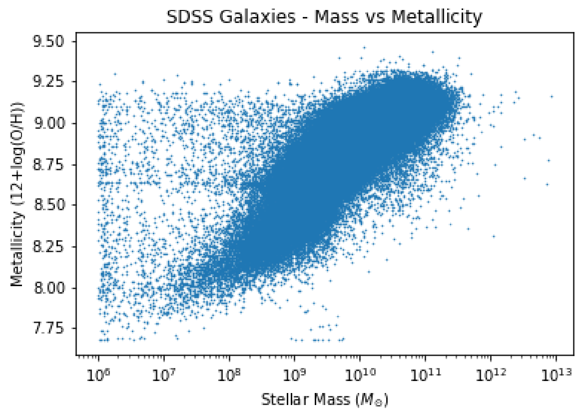

Figure 1: Gas-phase metallicity vs. stellar mass for SDSS galaxies.

The plot of metallicity vs. mass is shown in Figure 1. Invalid values (those less than zero) were removed from the data. The physical processes behind this trend could be that if a galaxy is more massive, it is more able to retain metals that would otherwise be ejected through supernovae and other processes. In addition, if a galaxy is more massive it would likely have a higher star-forming rate, which would in turn lead to a more metal-rich environment.

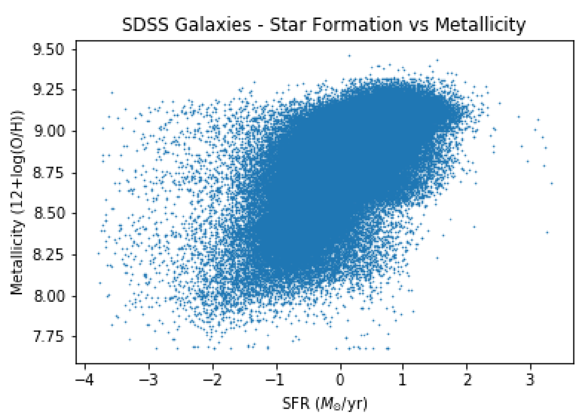

Figure 2: Gase-phase metallicity vs. (total) star-formation rate for SDSS galaxies.

(b) It has been suggested that metallicity is not only correlated with stellar mass, but also with the SFR of a galaxy. On the webpage given above you can find SFR measurements as well. Plot the gas-phase metallicity as a function of SFR. What can you conclude from this figure?

The plot of metallicity vs. SFR is shown in figure 2. Invalid values, recorded as -99 for the SFR data, were removed before graphing. From this graph, it would appear that the metallicity is also positively correlated with the star-formation rate.

(c) We know that stellar mass and SFR are well-correlated properties. Assess whether the SFR-metallicity relation just reflects the SFR-mass relation, or whether, independent of stellar mass, metallicity is correlated with SFR.

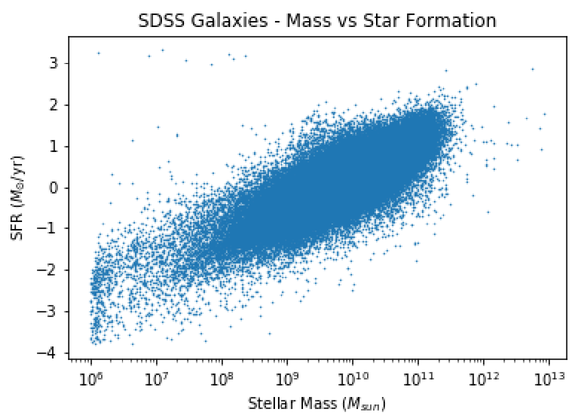

Figure 3: Star-formation rate vs. stellar mass for SDSS galaxies.

A graph of the star-formation rate vs. the stellar mass is shown in Figure 3. The data appears to be very well correlated from this graph. The plot for metallicity vs. mass seems to have a similar shape to that of the metallicity vs. the SFR, with a higher slope at lower x-values and an "elbow" feature in the middle. This indicates that at least some of the dependence of metallicity on star-formation rate can be explained by mass, as expected. However, the metallicity data has a much higher variance when plotted by SFR than it does when plotted by mass. If the metallicity had no secondary dependence on SFR, we would expect the metallicity and mass to be just as tightly correlated as the mass and SFR. Therefore, I think that there is a secondary dependence of the metallicity on the star-formation rate. For a more formal proof, I would calculate the partial correlation coefficient to remove the effects of mass from the metallicity-vs-SFR data. If this coefficient were above 1, it would be stronger evidence of a secondary dependence, but such a proof is outside the scope of this grad student's time limits.

(d) What could be the physical explanation of this possible secondary dependence?

One possible physical explanation for this secondary dependence could be the production and subsequent dispersion of metals by stars throughout the ISM. If two galaxies had the same mass, but galaxy A had a higher star formation rate than galaxy B, we would expect A to have a higher metallicity because of the increased fusion rates of metals in its young stars.

3. Magnitudes, Fluxes, and K-corrections

(a) Given the observed magnitude and redshift, what is the absolute (observed-frame) magnitude of this object in the g-band?

From class, we know that

$$DM = (m - M) = 5 \log \frac{d}{10\ pc}$$
$$M = m - 5 \log \frac{d}{10\ pc}$$

Where DM is the dispersion measure, M is the absolute magnitude, m is the apparent magnitude, and d is the distance to the galaxy. At low redshifts,

$$v = H_0 d$$
$$\approx c * z$$

From the galaxy's data, we know that $z = 0.10$, and that $m_g = 18.07$. Therefore:

$$d \approx \frac{cz}{H_0} = \frac{3x10^4\ km/s}{69.8\ km/s/Mpc}$$
$$\approx 5x10^8\ pc$$
$$DM = 5 \log \frac{5x10^8\ pc}{10\ pc} = 38.49$$
$$M = m - DM = 18.07 - 38.49$$
$$= -20.42$$

(b) Derive the observed flux densities F_λ and plot the observed broadband spectral energy distribution (SED).

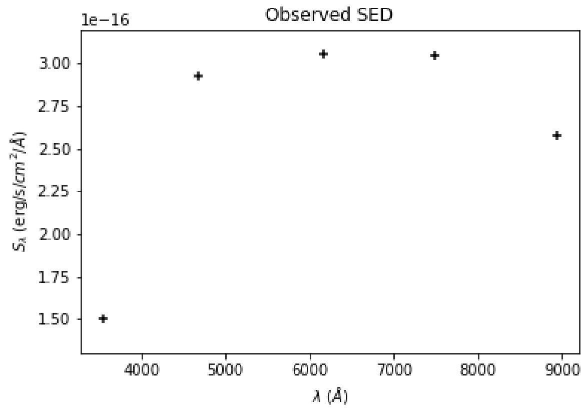

Figure 4: Observed spectral flux in each wavelength band, plotted as a function of wavelength.

We start with the magnitudes for each wavelength band, listed on the SDSS website. We know that

$$m = -2.5\log_{10}\frac{f_\nu}{f_0}, \text{ so}$$

$$f_\nu = f_0 * 10^{-\frac{m}{2.5}}$$

Changing units:

$$\begin{aligned} S_\nu &= f_\nu * \frac{c}{\lambda^2} \\ &= f_0 * 10^{-\frac{m}{2.5}} * \frac{c}{\lambda^2} \\ &= 3.631x10^{-20}\frac{erg}{s * cm^2 * Hz} * 10^{-\frac{m}{2.5}} * \frac{3x10^{18}\ cm/s}{\lambda^2} \end{aligned}$$

Plugging in the m and λ values for each wavelength band gives us the plot shown in Figure 4.

(c) Add the SDSS spectrum of the same galaxy to the figure made in b. The wavelength array information is stored in the header. Does the spectrum overlap with the broadband SED? If not, give an explanation for this offset.

The SED plotted against the full galactic spectrum is shown in Figure 5. There is a significant offset between the spectral energy density and the spectrum measured by the telescope. This is due to the fact that the magnitude values listed on the SDSS website for each wavelength band were calculated using photometry, while the spectrum was obtained with a spectroscopic instrument.

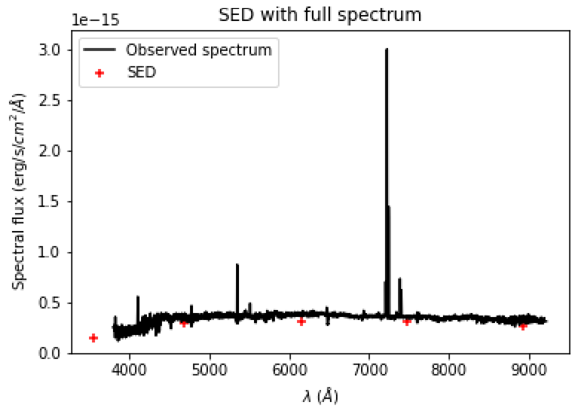

Figure 5: Full spectrum for galaxy J014207.20-002941.7 with SED points shown in red for comparison.

(d) Show the rest-frame spectrum in comparison with the observed spectrum in a new figure. Plot the g-band filter response function in the same figure, and explain your choice of response curve.

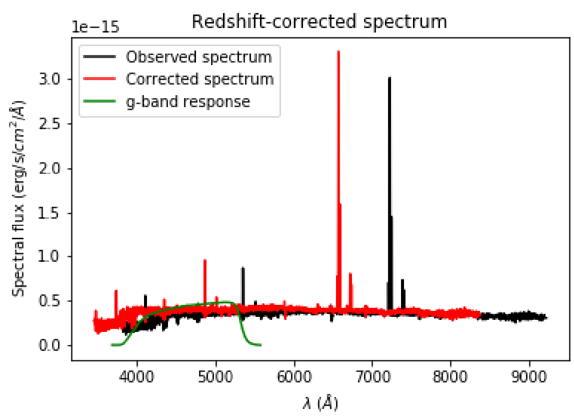

Figure 6: Rest-frame spectrum compared to the observed spectrum and the g-band response function.

To convert the observed spectrum to the rest-frame spectrum, we must divide the wavelength values by (1+z) $(1 + z = \frac{\lambda_{obs}}{\lambda_{em}})$ and multiply the flux values by (1+z). The resulting plot is shown in Figure 6.

(e) As is clear from the figure made in part d, the observed and rest-frame magnitudes will be different. Use the spectrum to calculate the K-correction in the g-band.

The K-correction in the g-band comes from integrating the flux density multiplied by the response function in the g-band:

$$F_{\lambda,g} = \frac{\int_0^\infty \lambda f_\lambda T_g d\lambda}{\int_0^\infty \lambda T_g d\lambda}$$
$$K_g = \frac{F_{obs}}{F_{rest}}$$

Approximating the g-band response function as a step function from a=4000 to b=5350 $\mathring{A}$ (based on graph values):

$$\begin{aligned} F_{\lambda,g} &= \frac{T_g \int_a^b \lambda f_\lambda d\lambda}{T_g \int_a^b \lambda d\lambda} \\ &= \frac{\int_a^b \lambda f_\lambda d\lambda}{\int_a^b \lambda d\lambda} \\ K_g &= \frac{\int_a^b \lambda f_{\lambda,obs} d\lambda}{\int_a^b \lambda d\lambda} * \frac{\int_a^b \lambda d\lambda}{\int_a^b \lambda f_{\lambda,rest} d\lambda} \\ &= \frac{\int_a^b \lambda f_{\lambda,obs} d\lambda}{\int_a^b \lambda f_{\lambda,rest} d\lambda} \end{aligned}$$

Using the trapz function from the numpy package, we can do these integrals to find $K_g = 0.834$.

(f) What is the absolute rest-frame magnitude of this object in the g-band?

$$\begin{aligned} M &= m - DM - K \\ &= 18.07 - 38.49 - 0.834 \\ &= -21.25 \end{aligned}$$

4. Luminosity and Mass Functions

(a) In class we wrote the Schechter function as a function of luminosity. Derive the equivalent function in terms of absolute magnitude, M.

The Schechter function is as follows:

$$\Phi(L)dL = \Phi_*(\frac{L}{L_*})e^{-\frac{L}{L_*}}dL$$

We know that:

$$\frac{L}{L_*} = 10^{-.4(M-M_*)}$$

so

$$\frac{d(L/L_*)}{dM} = \frac{d}{d(M-M_*)}(10^{-.4(M-M_*)})$$

$$\begin{aligned} dL &= \frac{d}{dM}[e^{ln(10^{-.4(M-M_*)})}]dM \\ &= \frac{d}{dM}[e^{-.4(M-M_*)ln(10)}]dM \\ &= -(-.4)l(10)e^{-.4(M-M_*)}dM \end{aligned}$$

therefore

$$\begin{aligned} \Phi(M)dM &= 0.4\ln(10)\Phi_*[10^{-.4(M-M_*)}]^{\alpha} * [10^{-.4(M-M_*)}]e^{(-10^{-.4(M-M_*)}}dM \\ &= 0.4\ln(10)\Phi_* 10^{-.4(M-M_*)(\alpha+1)}e^{-10^{-.4(M-M_*)}}dM \end{aligned}$$

(b) Figures

i. $Log(\Phi(L))$ vs $Log(L/L_*)$

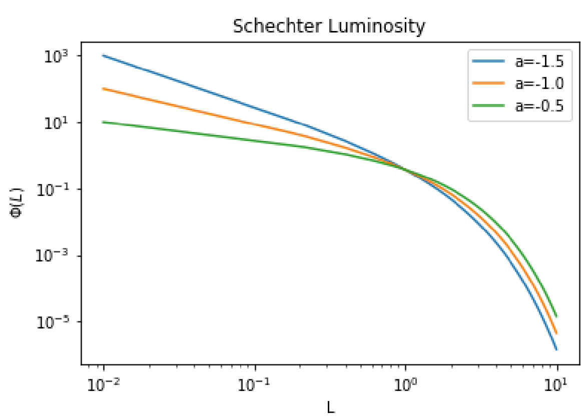

Figure 7: Schechter luminosity function vs. luminosity.

ii. $Log(\Phi(M))$ vs $(M-M_*)$

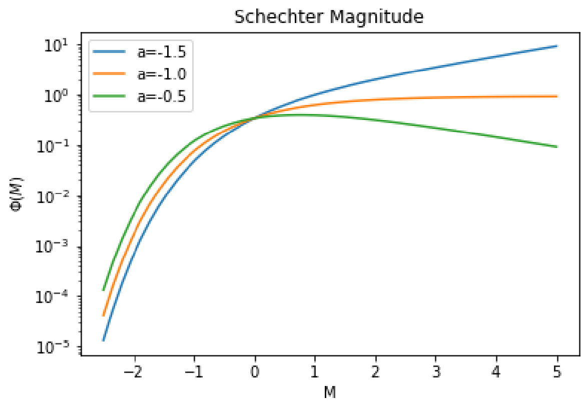

Figure 8: Schechter magnitude function vs. magnitude

iii. $Log(N(L))$ vs $Log(L/L_*)$

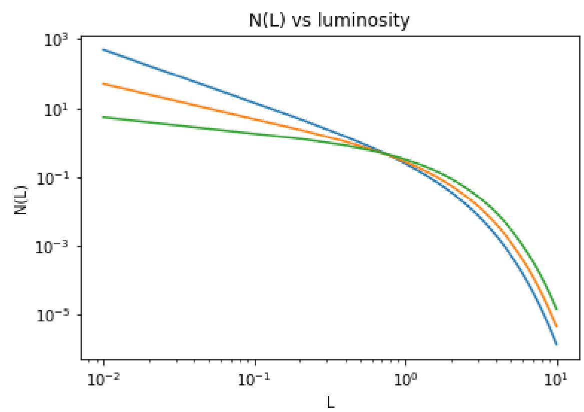

Figure 9: Integrated Schechter luminosity vs. luminosity

(c) The distribution of galaxies in terms of stellar mass can also be described by a Schechter function. However, the shape of the luminosity and mass function for the same selection of galaxies will be different. Please explain qualitatively why and how the shape changes when going from a luminosity to a mass function.

The shape changes from the luminosity to the mass function because elliptical and spiral galaxies have different Mass to Luminosity ratios in different wavelength bands. Elliptical galaxies have a much lower L/M at shorter wavelengths than spiral galaxies, so the shape of

$\Phi(M)$ would change for different wavelengths.

(d) Considering the stellar mass function, show in what types of galaxies most of the mass is locked up for different faint-end slopes.

Since $L \propto M_s$, we can assume that $\Phi(M_s)dM_s \propto \Phi_*(\frac{M_s}{M_{s*}})e^{-\frac{M_s}{M_{s*}}}dM$, where M_s is the stellar mass. The graph of this function will be nearly identical to that of the luminosity function:

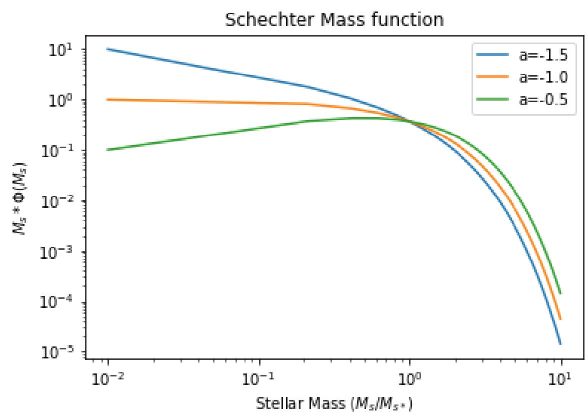

Figure 10: Graph of $M_s\Phi(M_s)$ vs. M_s/M_s*