Astrochallenge 2021

Data Analysis Question for Seniors (Take Home)

The Answer Sheet

Contents

1. Kinematics

a. **Can you think of other reasons that the velocity dispersion of disk-shaped galaxies would be hard to determine?**

The spectra of disk-shaped galaxies would comprise of spectral components of various stellar populations in the galaxy residing in different parts of it, complicating the analysis of spectral widening and calculation of velocity dispersion [1].

Velocity dispersion is usually computed by direct template-fitting with a fiducial spectral template, which can be the spectrum of an appropriate star, with spectral lines unresolved at the spectral resolution being used, or a combination of different stellar types, or a high S/N spectrum of a galaxy with known velocity dispersion[1]. Finding a template for a spheroidal galaxy of known star population would be easier and less computationally intensive than that for disk-shaped galaxies with multiple stellar populations [1].

The prevalence of a richer interstellar medium of gas and dust in a disk-shaped galaxy would lower the signal-to-noise ratio of such galaxies compared to gas and dust poor spheroidal galaxies [1].

- Any other reasonable explanations, with referenced sources if necessary [1].

Would the measured velocity dispersion be an accurate indication of the rotation of the galaxy's stars?

No [0.5] as the velocity dispersion does not give information about the orientation of a disk-shaped galaxy whose stars orbit in the galactic plane as opposed to that of spheroidal galaxies [0.5].

- Any other reasonable explanations, with referenced sources if necessary [0.5]

(While some teams used the reasoning that velocity dispersion is a measure of the dispersion of velocities about a mean velocity

[1] https://classic.sdss.org/dr7/algorithms/veldisp.html

and not a measure of the rotation of a disk-shaped galaxy, dispersion is still nonetheless a measure of the velocities in a galaxy and hence a larger velocity dispersion implies more stars[2] and/or stars orbiting the centre of the galaxy at larger velocities/ with a higher speed of rotation. You can then reason that more stars also imply a higher rate of rotation of the disk-shaped galaxy with the Tully Fisher's relation.

Hence this reasoning is not accepted, and teams would not be credited with 0.5)

b. **Why would the luminosity of these spheroidal galaxy systems that SDSS imaged be dominated by red giant stars?**

Spheroidal galaxies have collapsed from a large gas cloud and undergone rapid star formation in the past, depleting its gas supply and resulting in no recent star formation [3] [1].

Spheroidal galaxies could have formed from galaxy collisions which are more prevalent in the early stages of the universe, resulting in a burst of star formation which would have deleted their gas supply as of the present [1].

Supermassive black holes at the centre of large spheroidal galaxies may be stopping star formation in spheroidal galaxies as the cause the gas they heat up as they orbit the black hole and are not cool enough for star formation[4]. All that remains are many old red giant stars that have evolved from the main sequence [1].

- Answer must explain that the spheroidal galaxies are depleted of gas for new star formation and the idea that most stars in it are old stars which have evolved beyond its main sequence phase.

c. **Use the following queries to retrieve 100 objects from the specObj table with and without velDisp calculations respectively as .csv files and find the mean spectroFluxr / spectroFluxu, which group of galaxies are redder? Does this agree with the context?**

1 mark for correct calculation and retrieval of data, 0.5 mark for saying that the group of galaxies with *velDisp* calculations is

[2] https://arxiv.org/pdf/1804.10119.pdf
[3] https://astronomy.swin.edu.au/cosmos/E/elliptical+galaxy
[4] https://www.space.com/24815-supermassive-black-holes-star-formation.html

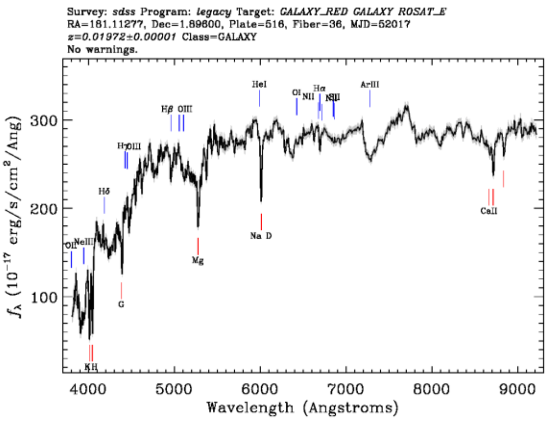
redder, 0.5 for relating it to the context of velDisp being calculated mainly for spheroidal galaxies whose luminosity are dominated by red giant stars.

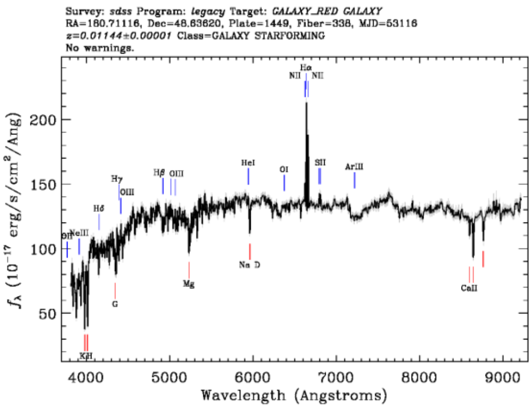
2. Colours

a. Which galaxy has a higher luminosity? Provide sufficient evidence from the spectra shown.

The first galaxy has a higher luminosity [0.5]

Read the wavelength for a specific emission/absorption line on the spectra and find the redshift of the galaxies [1].
(-0.5 for wrong calculations, see values of z below)





Show that even though the first galaxy shown in the diagram is further away by redshift, its spectra still as a higher overall spectral flux density/spectral irradiance [5] at almost every wavelength [0.5].
(Note that the vertical axis of the spectrograph does not represent intensity but spectral flux density, of unit intensity per unit wavelength. The intensity at each wavelength is hence the spectral flux density multiplied by the respective wavelength. Average spectral flux density can be calculated by integrating the area under the graph and then dividing by the wavelength interval, but such calculation is not necessary for the explanation.)

(Teams should try not to take many wavelength measurements to calculate the average redshift but rather take the most significant spectral line as some of the line markings are unclear.)

-Accept any other alternative explanation/reasoning for distance and relative brightness of the galaxies.

[5] https://en.wikipedia.org/wiki/Radiant_intensity

b. Why do the two galaxies seem to share the same strong absorption lines despite being so different in their spectrum?

The strong absorption lines (H & K, Na D) are characteristic of the interstellar medium and are the result of absorption of light from the galaxy by the interstellar medium which it passes through [0.5].
(The interstellar medium, while responsible for some of these absorptions, may not be thick enough to account for the strong absorptions.)

The absorption lines are the result of absorption of the galaxy's stars' light by chemical elements in their outer atmosphere. Despite having an abundance of cooler, older red giant stars which would show strong absorption lines produced by neutral/ionised metals in their atmosphere[6], the stars in the first galaxy are old population 2 stars that have a low abundance ratio[7]. While the second galaxy contains many young hot O and B stars, it also contains population 1 stars that are relatively cool and have high metal content in their atmosphere[8], resulting in considerable absorption lines despite having less luminous stars of these nature [1].

Metallicity:
http://www.astro.rug.nl/~ahelmi/galaxies_course/class_IV/class_IV-2005.pdf

The absorption lines are due to elements present in stars' atmospheres and that both galaxies have stars comprised of the same elements due to enrichment of the interstellar medium in the past by stars which have died and expelled their atmospheres into the interstellar medium [0.5].

(Either explain why the absorption lines are similar in strength or say they are not due to difference in abundance of relatively cool red stars in both galaxies [0.5].)

c. Which galaxy has more active star formation? Provide two evidence from the spectra.

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6 https://skyserver.sdss.org/dr1/en/proj/advanced/spectraltypes/lines.asp
7 http://adsabs.harvard.edu/full/1996MNRAS.278..841D
https://astronomy.swin.edu.au/cosmos/a/Abundance+Ratio
8 https://www.austincc.edu/jheath/Stellar/Hand/spvsel.htm

The second galaxy has a higher rate of star formation [0.5]

The second galaxy's spectrum shows higher relative intensity of Hydrogen Alpha emission lines, which are the result of hydrogen gas in star forming region being ionised by young, hot, new-born stars. [0.75].

Calculating the ratio of the relativity intensity at the u and r filter wavelength according to SDSS's colour classification scheme for the first and second galaxies respectively. Take the ratio of the two relative intensities to show that the second galaxy is bluer than the first, indicating that there are more young, bluer stars than that in the first galaxy [0.75].

- Any other reasonable explanations, with referenced sources if necessary [0.75]

3. Map

a. **Using Hubble's law (see Appendix) and the Hubble's constant of 69.3 km s-1 Mpc-1, calculate the absolute magnitudes under the various filters, create three new columns named M_u, M_r, and M_g beside your data for the absolute magnitudes.**

Correct use of Hubble's law to calculate distance [1]

Correct use of the distance and magnitudes formula [1]

Minus 0.5 for each of the following:
- wrong units
- wrong labelling of data
- calculation error

b. **Look at the above SQL query, why must the redshift values of galaxies queried be limited in such a way?**

Identify that the redshift values of the objects queried are between 0 and 0.1 or are low [0.5]

and acknowledge that this will simplify our relationship between Hubble's Law and the redshift galaxies without the consideration of relativistic effects [0.5].

OR

and state that this will ensure that the spectroscopic data of the galaxies are not so redshifted and hence still representative of their inherent emissions [0.5]

c. **Plot a graph M_u - M_r against M_g using a scatter plot. Adjust the horizontal scale to be between -25.0 and -15.0 and the vertical scale to be between 0.0 and 4.0 to capture the main plot of your data points.**

Correct axis values and labels [1]

Correct shape of plot with the right data ranges [0.5 each]

d. **From the graph you have plotted, do galaxies with higher visual luminosities seem to be bluer or redder? Suggest two reasons why this might be the case.**

Correctly identifies whether galaxies with higher visual luminosities seem to be bluer or redder ACCORDING to the graphs they have plotted [1].

Provide a reasonable explanation [1]

e. Can you identify different groups of galaxies within the cluster of data points, what are they? Draw red circles on your plot to identify the groups.

Circles groups with reasonable distinction [1]

Identify the groups circled [1]
e.g. red luminous elliptical galaxies, blue spiral galaxies, “green” galaxies with little gas supply and slowing star formation.