DISTANCES TO GALAXIES AND THE TULLY-FISHER RELATION
(ASTROPHYSICS OF GALAXIES)

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AIM

To study the distances to galaxies and the Tully-Fisher relation.

THEORY

The Tully-Fisher relation

The Tully-Fisher relation is a key empirical correlation observed in spiral galaxies, linking a galaxy's luminosity to its rotation velocity. Specifically, it states that the luminosity L of a spiral galaxy is proportional to the fourth power of its maximum rotation velocity $V_{\max}$:

$$L \propto V_{\max}^4$$

This relationship can also be expressed using the galaxy's absolute magnitude M and the width of its emission lines, which are related to its rotation velocity. The broader the emission lines, the higher the rotation velocity, and consequently, the greater the galaxy's luminosity.

The Tully-Fisher relation is valuable for estimating distances to galaxies and galaxy clusters. By measuring the rotation velocity and applying the relation, astronomers can infer the galaxys luminosity and, using known distance moduli or other distance indicators, derive its distance. This method provides a practical way to gauge distances to distant galaxies and clusters, contributing to our understanding of the large-scale structure of the universe.

PROCEDURE

- Select the first twenty spiral galaxies from the dataset provided to you.
- Correct the H I line width determined at 20 per cent of the peak level as per the inclination of each galaxy and obtain Wi.
- Use the corrected line width to account for self-extinction due to dust and gas in the same galaxy. You can apply the following relation: [1.57 + 2.75(log Wi - 2.5)] log(a/b). Here, a and b refer to the major and minor axes of the galaxy.
- Consider both self-extinction and Galactic extinction as per the data provided and obtain the corrected apparent magnitude for each galaxy.

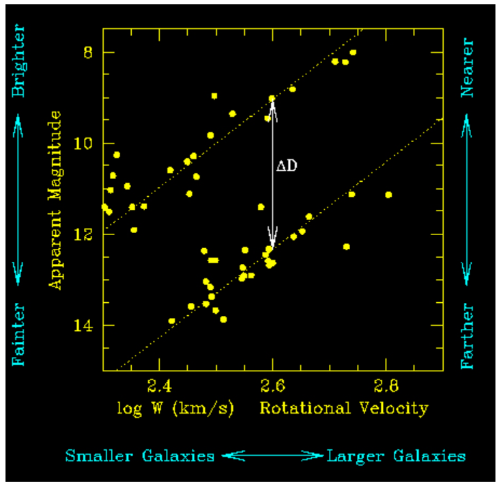

Figure 1: Tully-Fisher relation and distance between galaxy clusters

- Using the known estimates of absolute magnitude, determine the approximate distance in Mpc to each of the twenty NGC galaxies.
- Further, plot with uncertainties the absolute magnitude against the H I line width in order to represent the Tully Fisher relation. Determine the slope.
- Comment on your results.

ALGORITHM

1. **Import Libraries:**

   Import necessary libraries: pandas, numpy, and matplotlib.pyplot.

2. **Load the Dataset:**

   Load the dataset from an Excel file into a pandas DataFrame.

3. **Correct the H I Line Width for Inclination:**

   Calculate the corrected line width (Wi) by dividing the line width by the sine of the inclination angle (converted to radians).

4. **Account for Self-Extinction:**

   Calculate the correction factor using a given formula that includes the logarithm of the corrected line width and the log of the axial ratio.

5. **Apply the Correction Factor to the Apparent Magnitude:**

   Correct the apparent magnitude by adding the Galactic extinction and the calculated correction factor to the apparent magnitude.

6. **Determine the Distance Using the Corrected Apparent Magnitude:**

   Calculate the distance in megaparsecs (Mpc) using the corrected apparent magnitude and the absolute magnitude.

7. **Handle NaNs or Infinite Values:**

   Replace infinite values with NaNs and drop any rows with NaNs in the corrected line width (Wi) or absolute magnitude columns.

8. **Logarithmic Tully-Fisher Relation:**

   Take the logarithm of the corrected line width (Wi).

9. **Fit a Line to the Logarithmic Tully-Fisher Relation:**

   Use a linear fit (least squares polynomial fit of degree 1) to fit a line to the logarithm of the corrected line width versus absolute magnitude.

10. **Prepare Data for Plotting:**

    Create an array of x-values for plotting the fitted line using a linear space between the minimum and maximum of the logarithm of the corrected line width.

11. **Plot the Tully-Fisher Relation:**

    Plot the data points with error bars. Plot the fitted line. Label the axes and title the plot. Invert the y-axis to reflect the magnitude scale. Add a legend and grid for better visualization.

12. **Print the Slope and Intercept:**

    Print the slope and intercept of the fitted Tully-Fisher relation.

CODES AND OUTPUT

```
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt

# Load the dataset
file_path = '/content/tf-data.xlsx'  # Corrected path to your file
df = pd.read_excel(file_path)

# Correct the H I line width (Wi) for inclination
df['Wi'] = df['Line width'] / np.sin(np.radians(df['Inclination']))

# Account for self-extinction
df['Correction factor'] = 1.57 + 2.75 * (np.log10(df['Wi']) - 2.5) * df['log(a/b)']

# Apply the correction factor to the apparent magnitude
df['Corrected apparent magnitude'] = df['Apparent magnitude'] + df['Galactic extinction'] +
                                              df['Correction factor']

# Determine the distance using the corrected apparent magnitude
df['Distance (Mpc)'] = 10 ** ((df['Corrected apparent magnitude'] - df['Absolute magnitude']
                                              ) / 5 + 1)

# Ensure no NaNs or infinite values are present in Wi or Absolute Magnitude
df = df.replace([np.inf, -np.inf], np.nan).dropna(subset=['Wi', 'Absolute magnitude'])

# If the Tully-Fisher relation should be logarithmic, use log(Wi)
log_Wi = np.log10(df['Wi'])

# Fit a line to the log(Wi) vs Absolute Magnitude
slope, intercept = np.polyfit(log_Wi, df['Absolute magnitude'], 1)

# Create an array of x values for the fitted line
x_fit = np.linspace(min(log_Wi), max(log_Wi), 100)
y_fit = slope * x_fit + intercept

# Plot the Tully-Fisher relation
plt.errorbar(log_Wi, df['Absolute magnitude'], yerr=df['Error.4'], fmt='o', label='Data
                                              points')

# Plot the fitted line
plt.plot(x_fit, y_fit, 'r--', label='Fitted line')
```

```
plt.xlabel('Log(Corrected Line Width) (log(Wi))')
plt.ylabel('Absolute Magnitude')
plt.title('Tully-Fisher Relation')
plt.gca().invert_yaxis()  # Magnitude scale is inverted
plt.legend()
plt.grid(True)
plt.show()

print(f'Slope of the Tully-Fisher relation: {slope:.2f}')
print(f'Intercept of the Tully-Fisher relation: {intercept:.2f}')
```

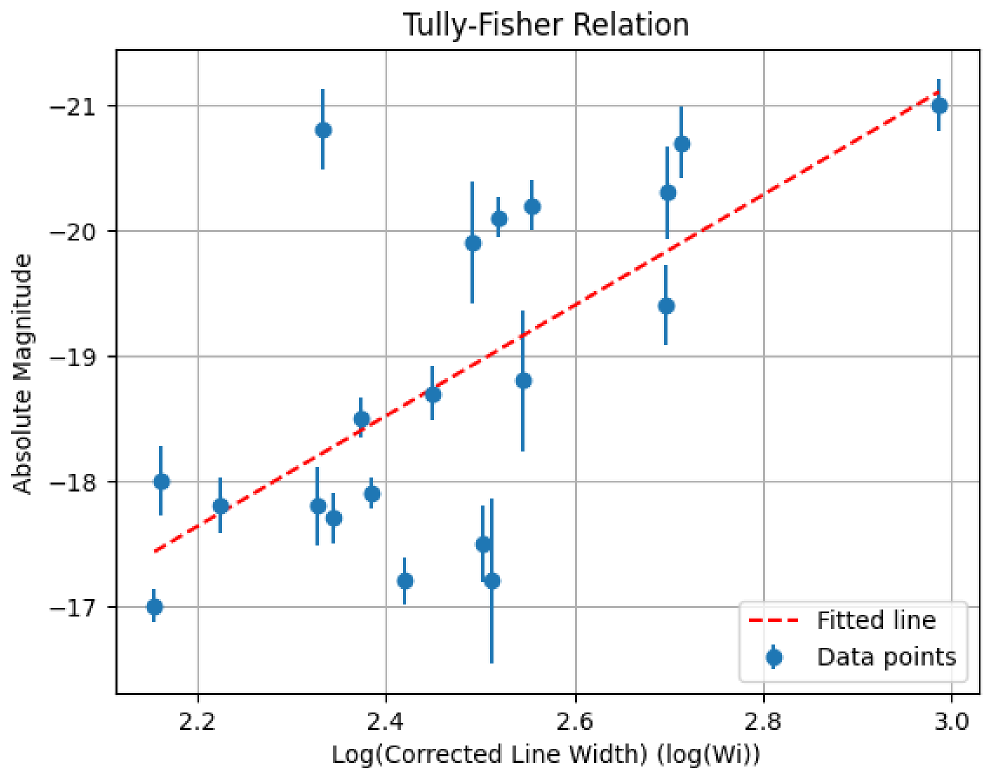

Figure 2: Slope of the Tully-Fisher relation: -4.41 & Intercept of the Tully-Fisher relation: -7.93

CONCLUSION

- A negative slope of -4.41 means that as the corrected line width (Wi), which is related to the rotational velocity of the galaxy, increases, the absolute magnitude of the galaxy becomes brighter (lower absolute magnitude value). The steep slope suggests that the galaxies in the dataset have a strong relationship between their rotational velocities and luminosities. This aligns with the general understanding that more massive galaxies (which rotate faster) tend to be more luminous.

- The intercept value of -7.93 represents the absolute magnitude of a hypothetical galaxy when the logarithm of the corrected line width (log(Wi)) is zero. While log(Wi) $= 0$ may not correspond to a physically realistic galaxy, the intercept provides a reference point for the fitted line.