Astrophysics 405 Homework Assignment 4

Tully-Fisher Galaxies in the Expanding Universe

Due 1999 April 15

This assignment is a "dry lab" simulation of a galaxy observation project. It provides real data from the research literature, upon which you will perform measurements and analysis. In place of telescopes and detectors, your tools will be a ruler, pencil, and calculator.

Images, spectra, and apparent magnitudes m_B for a collection of nearby galaxies have been provided. The images are scanned R-band photographs extracted from the Digital Sky Survey database; larger versions are available at **www.ras.ucalgary.ca/~gibson/asph405**. The spectra are neutral hydrogen 21cm emission line profiles obtained with the Green Bank 300-ft. and 140-ft. radio telescopes by Brent Tully and Rick Fisher for their original research. Some spectra contain foreground Milky Way HI emission or absorption near 0 km s^{-1}, which should be ignored.

1. For each galaxy, carry out the following steps. Report your results in a table for the entire set, supplementing with explanatory notes on calculations where appropriate. Also summarize and explain the amount of error you feel is associated with each result.

   (a) Measure the mean radial velocity of the galaxy.

   (b) Measure the apparent minor/major axial ratio β/α; this is the complement of the ellipticity used in the Hubble classification scheme (Equation [23.1] in the text).

   (c) The apparent magnitude m_B needs to be corrected for dust extinction to accurately represent the luminosity of the galaxy. This extinction is the sum of two components: A_g from foreground Milky Way dust, and A_i from dust internal to the target galaxy. Estimate each component:

      i. $<A_g> \simeq 0.4\ B$ mag at the Galactic poles; for this exercise, assume an infinite, plane-parallel Galactic "atmosphere" to find A_g as a function of Galactic latitude b. This approximation has two main flaws: (1) the distribution of dust in the ISM is lumpy, not smooth, and (2) the Milky Way's disk has an outer edge. The latter is not a concern for this galaxy sample, while the former has been glossed over for simplicity.

      ii. A plane-parallel model won't work for A_i, since many of the galaxies in this set are viewed close to edge-on. Instead, use the relation

$$A_i = 0.40 \cdot (\alpha/\beta - 1)$$

      and the axial ratio found above. This corrects the galaxy to a face-on orientation but leaves the "one airmass" internal extinction in place, since it is incorporated in the standard Tully-Fisher empirical calibrations.

(d) Assuming the galaxy has a circular disk, calculate the angle ξ by which the plane of the disk is tilted with respect to the plane of the sky. Use Erik Holmberg's formula

$$\cos^2 \xi = \frac{(\beta/\alpha)^2 - r_0^2}{1 - r_0^2} ,$$

where $r_0 = 0.20$ is the assumed axial ratio for a system seen completely edge-on.

(e) Measure the HI line full width at half maximum (FWHM). From this, calculate the maximum rotational velocity $V_{\rm max}$ of gas in the galaxy, correcting for the projection effects (think carefully about how your angles are defined!).

(f) Calculate the absolute magnitude M_B via the Tully-Fisher relation, using Equations [23.4] in the text. Where possible, choose the equation whose Hubble type best matches that of the galaxy; assume Sa if the object appears earlier than Sa, and Sc if later than Sc. For those galaxies you are unable to classify, assume type Sc.

(g) Compute the T-F distance for each galaxy.

2. Make a plot of radial velocity vs. distance for the entire dataset. Do the data show a linear relation? If deviations from linearity are present, are they within the scatter you might expect from the uncertainties you estimated, or do they show evidence for acceleration or deceleration? (Note that the Universe has been "adjusted" for this exercise to make possible significant cosmological measurements which normally would not be readily obtainable for such a local sample of galaxies.)

3. Calculate the Hubble constant H_0 based on these data. If there is evidence for a non-unity acceleration/deceleration term q_0, calculate that as well, using text Equation [27.100], neglecting terms higher than 2nd-order in redshift. The ambitious can perform a full χ^2-minimization to find the best values of q_0 and H_0, but all that is required here is a fit which looks reasonable to the eye.

4. Assume $\Lambda = 0$ to find Ω_0 from q_0. What is the geometry of the Universe according to your measurements? What does this predict for the ultimate fate of of the cosmos?

5. Use this result to estimate the age of the Universe t_0 from text Equations [27.35-37], selecting the expression appropriate for the geometry you have found. Show how this expression derives from the Friedmann Equation ([27.8]), i.e., carry out the parts of Problems [27.4-7] and [27.10] in the text which apply to this geometry.

6. Are your results for H_0, q_0, Ω_0, and t_0 consistent with currently held estimates? Would you reasonably expect to be able to measure all of the quantities you have here with a similar dataset for the "real" Universe? Why or why not?

Galaxy Data

Use the following data in your calculations. There are 32 galaxies in this sample. Images and HI 21cm line spectra are given on subsequent pages. Some of the 21cm spectra are for galaxies not included in the sample, and can be ignored.

Name	Coord (l, b)		m_B
NGC 2366	146.42°	+28.54°	11.49
NGC 3556	148.32°	+56.26°	10.45
NGC 3782	154.44°	+65.96°	13.77
NGC 3877	150.72°	+65.96°	10.52
NGC 3893	148.15°	+65.23°	9.67
NGC 3917	143.65°	+62.79°	11.53
NGC 3953	142.21°	+62.59°	9.74
NGC 3972	138.85°	+60.06°	12.66
NGC 3992	140.09°	+61.92°	8.68
NGC 4010	146.68°	+67.36°	12.35
NGC 4013	151.86°	+70.09°	11.33
NGC 4085	140.59°	+65.17°	11.08
NGC 4088	140.33°	+65.01°	10.52
NGC 4100	141.11°	+65.92°	10.90
NGC 4157	138.47°	+65.41°	11.03
NGC 4178	271.86°	+71.36°	9.68
NGC 4183	145.39°	+71.73°	13.44
NGC 4192	265.44°	+74.96°	10.95
NGC 4206	270.20°	+73.55°	12.60
NGC 4217	139.90°	+68.85°	10.63
NGC 4236	127.41°	+47.36°	10.05
NGC 4498	277.92°	+78.75°	12.80
NGC 4501	282.33°	+76.51°	9.71
NGC 4532	291.02°	+68.94°	14.52
NGC 4535	290.07°	+70.64°	10.19
NGC 4651	293.07°	+79.12°	7.71
NGC 4654	295.43°	+75.89°	9.79
NGC 4758	304.53°	+78.72°	14.06
NGC 5204	113.50°	+58.01°	11.02
NGC 5585	101.00°	+56.47°	10.26
IC 769	269.74°	+72.44°	12.00
IC 2574	140.20°	+43.60°	8.75