Problem Set #1: The Malmquist Effect

Parts 1 and 2 due by Monday, September 14 in class
Final Write-up due by Friday, September 18 by 5pm to Dickinson 104

*Note: Please complete this problem set on your own, without working with your classmates. If you have questions or need help, please ask me. Please read the information below **carefully**.*

The local universe contains galaxies with a wide range of luminosities, from M_B=-10 to -22 (for comparison, the Milky Way has M_B=-20). For this exercise, we will assume that the galaxies are distributed **homogeneously**, that is, there are equal numbers of each type and luminosity in any given volume of space (we *know* that this is not true in detail, but we'll ignore that for now).

Imagine that you carry out a survey of galaxies where you observe exactly 1% of the sky (413 square degrees). The survey is done in a region where Galactic absorption due to the Milky Way is negligible. All galaxies that possess apparent magnitudes $m_B \leq 15.0$ (i.e. **brighter** than 15.0) are included in the resulting catalog. This is a sharp magnitude cutoff – no galaxies fainter than this limit are included. Your survey is, therefore, a **magnitude-limited sample**, and suffers from the *Malmquist effect*. The following exercise is meant to help you explore/consider/ visualize this effect and the biases it produces in galaxy catalogs.

In the table below, you are given the volume densities ϕ of galaxies for seven different luminosities. These are the numbers of galaxies per cubic Mpc with the given absolute magnitudes (the quantity ϕ counts all galaxies in a 1 magnitude wide range centered on the listed M_B, so the units of ϕ are really number/Mpc^3/ magnitude). The values in the table are representative of the *true space density* of galaxies (note that there are many more low luminosity galaxies than there are giant galaxies).

1) For each row of the table, calculate the distance D (in Mpc) out to which your survey would detect a galaxy of that absolute magnitude. That is, for a galaxy with an apparent magnitude equal to the faintest allowed by your survey (i.e. $m_B = 15.0$), how far away would you see it? Enter the values into Column (3) of the table and show your work on a separate page.

2) Calculate the volume V (in Mpc^3) within which you could see a galaxy with m_B equal to the survey limit (15.0) and M_B equal to the value listed in each row. This is just the volume of a sphere of radius D, reduced by a factor 0.01 to account for the fact that your survey only covers 1% of the sky. Compute V for each of the seven luminosity values listed on the table and enter them in Column (4), again showing your work on a separate page.

3) Now, compute the number of galaxies of each luminosity that your survey should detect. This is simply the product of the volume density ϕ and the

volume V. Since one cannot have fractional galaxies (at least under normal situations), round your answers to the nearest integer. Enter the values into the 5th column of the table.

4) If it were possible for you to obtain a **volume-limited sample**, then the number of galaxies you cataloged would include all those within your survey volume. The number detected at each luminosity would again be the product of ϕ and the volume of your survey. However, in this case the volume V would not vary from one luminosity bin to the next. Suppose you had a volume-limited survey that covered 10,000 Mpc^3 (this corresponds to D=62 Mpc if the area stays the same as the original survey)[1]. Compute the number of galaxies you would detect in such a survey at each luminosity listed on the table. Enter the numbers in column 6.

   Carefully consider the results in columns 5 and 6, and discuss what you think they mean. Your response should include, but need not be limited to, answers to the following: How do the numbers change relative to each other as the luminosity changes? Does this make sense to you? How "complete" are typical magnitude-limited samples at the various luminosities? Sum the numbers in each of the two columns and compare the total numbers contained in the two surveys. What fraction of the galaxies in the hypothetical volume-limited survey is contained in the magnitude-limited survey? Comment on how representative our current magnitude-limited catalogs are of the overall galaxy population.

5) Compute the apparent magnitude m_B that a galaxy with the luminosities given in the table would have if it were at a distance equal to the outer edge of the volume-limited survey. Record these magnitudes in Column (7) of the table. This is how faint your survey limit would have to be in order to include all galaxies with that absolute magnitude. Include the values in the table, again showing all work on a separate page. Comment on the results (*Hint: what is the faintest object found in the SDSS – the largest survey of galaxies to date?*). Do you see why volume-limited surveys are virtually impossible to obtain?

Remember: Show all work on the numerical parts, and clearly justify your answers on discussion parts. Turn in the attached table, along with your written answers.

[1] This distance would represent a fairly "nearby" survey. It would include lots of galaxies, but would tell us very little about anything other than the relatively local universe.

M_B	ϕ [Mpc^{-3}]	Distance – D [Mpc]	Volume – V [Mpc^3]	Number Mag. Limited	Number Vol. Limited	m_B
(1)	(2)	(3)	(4)	(5)	(6)	(7)
-10.0	0.2528					
-12.0	0.1264					
-14.0	0.0632					
-16.0	0.0316					
-18.0	0.0158					
-20.0	0.0042					
-22.0	0.000016					