EXERCISE II. Star Counting in Herschel's Universe

In this exercise the basic shape of the Milky Way Galaxy is explored by counting stars in different parts of the sky. This experiment follows in the footsteps of the astronomer William Herschel (1738 – 1822) who counted stars in several thousand areas of the sky and deduced the disk-like shape of our Galaxy.

We shall use a few of Herschel's assumptions about the stars to obtain a simple but useful picture of our local universe. Let us assume that all the stars that we see are distributed uniformly in space. This means that there are as many stars in one volume of space as in any other region of equal volume. We assume also that the stars all have much the same true brightness (absolute magnitude).

If we choose a square of space on a photograph then we are viewing all stars within a pyramid-shaped volume of space, as shown in figure 4.5. The first thing to note is that there are more fainter stars than brighter stars because a) stars appear fainter with distance and b) the volume observed (and so number of stars) increases by the cube of the distance. If stars at distance r_1 have brightness B_1 and stars at distance r_2 have brightness B_2 then the inverse square law tells us that $B_1/B_2 = (r_1/r_2)^2$. The total number of stars just depends on the volume of space, which is proportional to r^3. If the total number of stars within the volume out to r_1 is N_1 and the total number seen out to r_2 is N_2 then

$$\left(\frac{r_1}{r_2}\right)^3 = \frac{N_1}{N_2}. \tag{4.1}$$

So we have simple relationships between the brightness and total number of stars within a certain volume specified by distance r and the area of sky under study. We can combine these relationships to give

$$\frac{B_1}{B_2} = \left(\frac{N_1}{N_2}\right)^{3/2}. \tag{4.2}$$

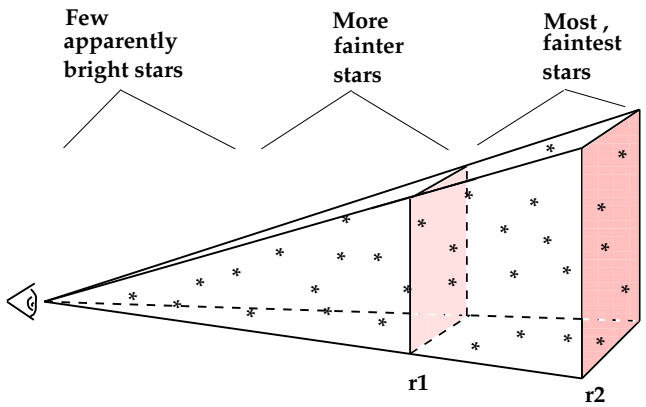

Figure 4.5: *The growth in number and faintness of stars with survey depth.*

Method.
Choose two, or more, films of areas of the sky at different galactic latitudes. Now carefully mark identically sized zones on each of the chosen films taking care to avoid obscuring dust clouds or bright nebulae in the low latitude fields and any large galaxies in the high latitude fields. Examine each area with a magnifier and it will be seen that most faint objects close to the Milky Way are stars whereas many of the faint objects in high latitude fields are very faint, distant galaxies.

Ideally all star images in each zone would be counted. However, it is extremely difficult to distinguish stars from galaxies for the faintest objects and the statistics will be wrong if galaxies rather than stars are counted. This problem can be avoided by only counting stars brighter than a particular magnitude. This can easily be done by counting only those stars which have diffraction spikes (i.e stars brighter than about magnitude 15), or some other easily distinguished feature such as the 1mm halo around stars brighter than magnitude 11.

Now compare the counts for different galactic latitudes. The counts should show that there are many more stars in the fields close to the galactic plane (those with $b < 10°$) than in the high latitude fields ($b > 50°$). Our galaxy is therefore similar to the spiral galaxies which can be seen on some of the films. Herschel pictured this as a disk or 'millstone' (see figure 4.6). He was not able to measure the distance of the stars but was able to estimate the relative thickness of the Galactic disk compared to its diameter. You should be able to do the same using equation 4.1.

Hint: The high latitude field is looking out of the disk, so measures its thickness; the Milky Way fields look into the disk, so measure its width.

Modern measurements suggest that the our Galaxy is about 20 - 30 times thicker than its width. This is far more than Herschel's model would have us believe. The reason for this discrepancy is that inter-stellar space contains regions of dark dust clouds which hide the light from background stars, leading to false star counts. These dark clouds are explored in exercise III.

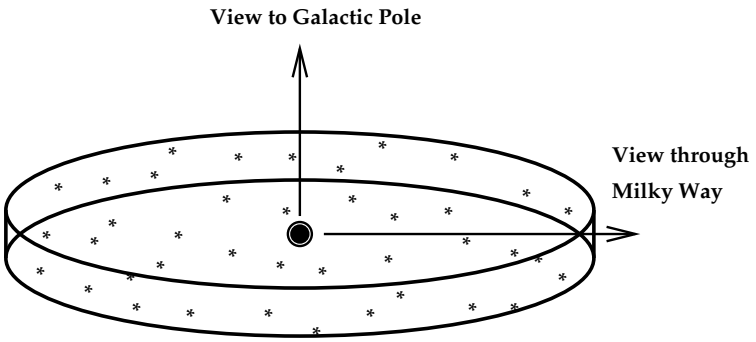

Figure 4.6: *Herschel's 'millstone' disk model of the Galaxy with the Sun near the centre.*