Interstellar Extinction

Observational Astronomy

1 Introduction/Background

The space between stars in the plane of the galaxy is not empty. Contained within is obscuring material[1] consisting of gas and dust grains. There are many dark clouds of this material in the Milky Way that obscure light from stars behind them, making these stars appear dimmer than they are. The largest such cloud is known as the 'Coalsack', an area in the southern sky where the dimming of large amounts of stars is evident to the naked eye. A similar cloud, whose obscuration is obvious to the human eye and is visible in the northern hemisphere, is a cloud known as the Rift in the Cygnus.

The dimming of light in the galactic plane due to these clouds varies based on line of sight but, on average, it will be about 1 mag$\cdot$ kpc^{-1} (magnitude per kiloparsec). So, a star that is 1 kpc away in the galactic plane will appear to be 1 magnitude dimmer than it really is; a star that is 2 kpc away will appear 2 magnitudes dimmer, and so forth. A magnitude is equivalent to a factor of about 2.5 in brightness; extinction of 1 magnitude will show the star as being 2.5 times fainter than it really is or that its light has been reduced to 40% of its original intensity. This implies that light traveling 2 kpc is reduced by a further factor of 2.5 to 0.4 x 0.4, or 0.16, of its original brightness. Due to this extinction effect, the inner parts of our galaxy, being many kiloparsecs away, are dimmed to invisibility.

Any stars that are seen through these clouds appear not only dimmer, but also redder. The reddening is not caused by an increase in the amount of red radiation; rather, it is an effect of the scattering properties of the dust in the cloud. Scattering by the interstellar dust is more efficient at the shorter wavelengths, meaning that more of the redder light gets through the intervening cloud. There is an observed relation between wavelength of radiation and corresponding levels of extinction, known as the 'extinction law', that shows that magnitudes of extinction increase linearly with the inverse of wavelength or $1/\lambda$. Infrared and radio wavelengths are thus extremely useful for studying the interior regions of our galaxy.

The scattering material in these clouds is considered to be a set of solid dust grains approximately 0.3 microns in size. These grains scatter the light, reflecting it in all directions, with a small fraction of the radiation being absorbed by the grain. Light of shorter wavelength is scattered more from its original path. Detailed studies using infrared spectroscopy have shown that these scattering materials consist mostly of silicates and graphite.

[1] This is generally known as the interstellar medium, or ISM.

2 Coalsack Images

For the purpose of this lab you will need to download the images of the Coalsack region in three different wavelengths. These can be found at the course website for Intro to Astronomy & Astrophysics:
http://www.rpi.edu/dept/phys/Courses/ASTR2050/sackBlue.jpg
http://www.rpi.edu/dept/phys/Courses/ASTR2050/sackRed.jpg
http://www.rpi.edu/dept/phys/Courses/ASTR2050/sackIR.jpg
The images for the Coalsack will be in three different wavebands: Blue (420 nm), Red (640 nm), and IR (800 nm).

3 The Extinction Law

There are two categories of stars that we will be looking at in the direction of a dark cloud[2]: field stars, which are not blocked by the cloud; and obscured stars, which are being extincted by the intervening cloud. It is not obvious just by looking which stars are closer than the cloud and which are further because the distance of the cloud is not something that is obviously deduced. A common rule of thumb is that a cloud with a well defined outline is relatively close to us, on the order of a few hundred parsecs. The Coalsack has been found to be about 200 parsecs away from us, based on distance observations of individual stars in the region. This leads us to be able to assume most of the stars in the obscured region are actually further away than the cloud, suggesting that most of them are being extincted by the cloud.

The density of stars in a general field of view increases as you count to fainter magnitudes. The star density in the region of the cloud also increases with magnitude at the same rate, but all the magnitudes will be fainter than the surrounding regions due to the intervening cloud. If it is known how the density increases with magnitude[3], then the difference in density between field and obscured stars can be used to determine the difference in magnitude between the stars in the two regions. This value for the general field is that the log of star density increases by 0.4 per magnitude, and is assumed to be the same at all wavelengths.

4 Measuring Extinction - The Star Counting Method

The images have been previously processed, so the contrast should already be at a good setting for counting purposes. If you do feel you need to alter the images settings to allow you to make better counts, you can adjust this by using the ‘screen stretch’ window.

Choose an area within a cloud of conspicuous obscuration on one of the photographs. The area should be as large as possible to maximize the accuracy of the count, but its shape

[2]This excludes stars that are ‘embedded’ in the cloud, but we can ignore them because they won’t have a significant effect on the statistics.

[3]This value is log (N/N_0), where (N/N_0) is the ratio of stars per area in the field vs. obscured regions.

is irrelevant. Choose a window of a convenient size and shape and outline it over the area you want to count. Now decide on the faintness to which you think you can count and choose a limit by the size of the images. The fainter you count, the better the accuracy of the counts from the statistical point of view; however it is also essential that you are able to recognize the limit consistently (It may take a minute or so to get used to counting the stars on these images).

Outline the window on the cloud and count all the stars to the chosen limit. Move the window to a comparison field away from the cloud, and count again. There are so many stars in the unobscured areas that you may need to subdivide the area in order not to lose count. Repeat this in a number[4] of other comparison areas and take the mean. The more comparison fields you use, the better the accuracy of the mean.

Obtain the ratio of field stars (N) to obscured stars (N_0), and take the log of this ratio. (Note that the area of the window does not enter into the calculations.) Knowing how the density of stars changes with magnitude an expression can be obtained for finding the extinction:

$$\frac{\log(N) - \log(N_0)}{\Delta m} = -0.4$$

From the known rate of increase in log (N/N_0) calculate the magnitude difference corresponding to the log of the ratio of field to obscured numbers which you have counted. This magnitude difference is the extinction.

5 Density of Grains in the Line of Sight

Given the dimensions of the grains and their scattering properties it is possible to calculate the density of grains in a dark cloud. The effect of scattering may be described in the following way: If a grain is a sphere of radius a, its cross-sectional area in the path of the light is πa^2. When scattering takes place the amount of light removed by the grain is πa^2Q, where Q depends on the wavelength and the size of the grain. Q is greater than 1 for short wavelengths, while the grain behaves as if it were larger than its actual geometrical size. For long wavelengths Q is less than 1 and the grain behaves as if it were smaller than its actual size.

For our estimate of the numbers of grains causing the extinction we assume that in the blue waveband the grains behave approximately like simple obstructions in the path of the light from stars behind them. The remainder of the light (apart from a small fraction which is absorbed by the grains) passes through in the spaces between the grains. The amount of light intercepted per unit area is proportional to the number of grains per unit area in the line of sight. If there are n grains per unit area in the line of sight, their combined area is πa^2n and the unobscured area is (1-πa^2n) of a unit. The ratio of the light which gets through to the original light is (1-πa^2n). Expressed in magnitudes, the extinction is 2.5 times the

[4]Stick to doing three different areas for each count if you have time.

logarithm of this quantity (with the sign changed according to convention). In algebraic form the extinction is:

$$\Delta \text{ m} = -2.5\log\,(1-\pi a^2 n)\text{ mag}$$