The Disc of the Milky Way Galaxy

Aim

In this experiment you will take spectra of HI from the Milky Way galaxy. In particular you will make observations that will support the existence of spiral arms and demonstrate that the Milky Way is a disc-like structure.

Introduction

In experiments where we scan across a source we often observe sources over a finite bandwidth of the spectrum and measure the *total* power of the signals. Here we will investigate the variation in power over the bandwidth i.e. the spectrum.

Differential galactic rotation means that, along any given line of sight through the Milky Way (our own galaxy) different regions of HI gas we observe will be moving with different radial velocities with respect to us. Therefore, the spectra we expect will be spread about the intrinsic H-line frequency due to Doppler shift producing a profile which varies in appearance for different regions of the galaxy. To measure these HI profiles, we pass the signals into a high-speed sampler from which we can use a fourier transform technique to obtain a spectrum of the radio emission.

When plotting spectra, it is convenient to work in temperature (or the equivalent flux density) on the y-axis and velocity (computed using the non-relativistic Doppler formula) on the x-axis. A useful "rule-of-thumb" is that, at this observing frequency (approx 1420 MHz), a 5 MHz bandwidth corresponds to a velocity width of approximately 1000 km/s.

All the spectra you will measure are in fact rather weak and are superimposed on a large system temperature which has a non-linear band-pass shape. We require some way of subtracting this, leaving just the spectra. One way of doing this would be to point the telescope on-source, integrate for a finite time then move a few degrees off-source and subtract the two spectra. Whilst this "*position switching*" method is fine for extragalactic observations, when looking at galactic HI there is virtually no clear part of the sky. In this case, we change the frequency of the system whilst pointing at the same position. Such a "*frequency switching*" mode can be achieved by changing the frequency of the local oscillators. In this case the background spectrum which is subtracted is then just a section of the spectrum to one side of the 1420.406 MHz emission line region.

The total bandwidth available to us is 5 MHz so we can observe a velocity range of about 1000 km/s. The frequency of the first local oscillator determines which part of the 5 MHz bandpass we are looking at and hence the frequency (or velocity) of HI that we observe.

1. A spectrum from galactic position (120,0)

For your first observation of HI in the Milky Way we will select a position in the galactic plane which is visible all the time from Jodrell Bank (technically objects like this that never set are called circumpolar - they rotate around the celestial pole without ever going below the horizon). In galactic coordinates a good choice would be a longitude of 120 degrees and latitude of 0 degrees. The latitude ensures we are exactly in the plane of the galaxy, whilst the longitude is chosen to ensure the position is never below the horizon.

*Use the **Source Track** utility to check that (120,0) never sets. Try a few different times of the year to see how the elevation varies or a few different longitudes to see the effect.*

You will now need to check using **Schedule** what slots are available - an on-source integration time of 120 seconds should be sufficient so you should only need one slot (the observation will take about 5 minutes: 2 mins on source plus 2 mins on reference plus about 1 min for calibration overheads etc). You will need to pick a slot a little in advance of the current time (you can find out the current time according to the telescope by looking at the **Monitor** page) - say more than 10 minutes ahead to give time for you to confirm it (see below) and for the software to insert the observation into the telescope queue.

[**Note**: Occasionally you may find your observation never completes (i.e. remains at status 2 or 3. This is usually because the telescope may be pointing in a completely different direction to the one you want before you start your observation. It then takes longer than the 10 minute slot to slew around to your position. An easy way round this is to allocate two 10 minute slots. The slew speed is about 20 degrees per minute so it's possible for the telescope to take 10 minutes to get round half the sky.]

When you use **Observe** to define the observation you will be setting up a frequency-switched observation. Hence the reference coordinates should be the same as your target coordinates and you should set a frequency offset of -3 MHz.

You should also set the source velocity to zero as we do not know what velocity to expect in this case (setting it to a non-zero velocity simply changes the local oscillator frequency to one that places the Doppler-shifted HI frequency in the middle of the passband).

Once you have inserted your observation in the queue check the details from the **Schedule** page. If you're happy click on *submit*. Status should change from 0 to 1 and then, if the observation is successfully queued, to 2 a few minutes later (you'll need to *refresh* the page to check if the status has changed).

You should be able to use the monitor to watch your observation and when it is completed the status should change to 4 and the data should then be available for viewing in the **Archive** page.

1.1 Results/Analysis

The HI line profile should show a curving background level with a large peak of emission due to hydrogen around a frequency of 1420.4 MHz. Compare your observation to the one shown in the **Manual** document (linked from the menu bar) as these are at the same coordinates and should appear very similar. Any differences are likely to be due to interference at one or other of the observation times. This peak should show some structure due to Doppler shifts of hydrogen in several spiral arms along that line of sight through the galaxy.

For the first spectrum at (120,0) you should compare the frequency scale on the spectral bandpass plot with the velocity scale obtained by selecting *velocity* on the plotting applet just below the graph. You should convince yourselves that this is obtained by using the Doppler shift formula.

Measure the velocities of each of the peaks in the main profile. Each of these peaks corresponds to a separate spiral arm structure in this particular direction within the galaxy.

Look at the schematic picture of the spiral arm structure of the Milky Way in your notes (reproduced below) and work out which spiral arm corresponds to which peak in your spectrum.

[In the model shown in the diagram we assume that the galactic disc rotates at a constant speed of V_{rot}. Note that the Doppler shift of a given arm is then just $V_{rot}\cos a$ where a is the angle between the line of sight and the V_{rot} velocity vector. The angle a is shown for the Sun's position but gradually increases for clouds/arms farther along the line of sight. Hence the cosine of this angle reduces and so the component of velocity of a given cloud along the line of sight (e.g. V_2 for cloud 2) reduces as one moves farther along the line of sight. Remember that the velocity plotted on our spectra is the relative velocity between ourselves and the cloud i.e. V_2-V_s for cloud 2.]
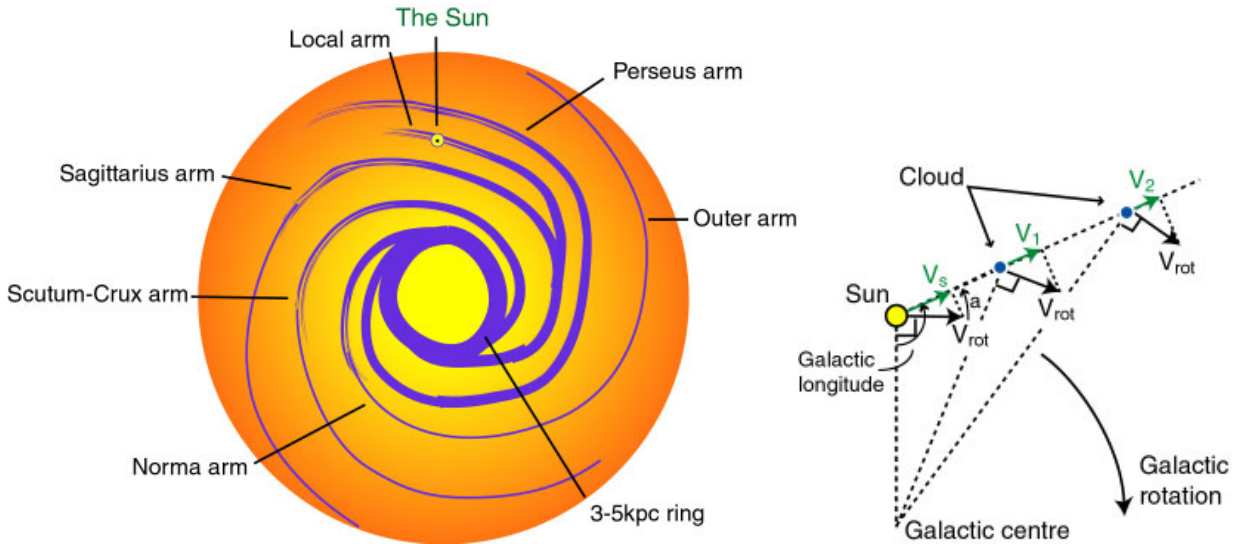
2. Spectra at different longitudes

In the above model what should you expect to see from positions (180,0) (i.e. looking upwards in the above diagram, directly away from the galactic centre) and (240,0) (i.e. looking towards the left in a reflection of the 120 degree longitude direction)?

Take a spectrum from each of these positions (remember to check when they are above the horizon) and explain the structure that you observe.

3. Hydrogen spectra as a function of galactic latitude

You should now investigate the Milky Way's disc of neutral hydrogen by taking spectra at different galactic latitudes but the same longitude as the first spectrum (120 degrees). Remember the beamwidth means there's no point in steps less than a few degrees but you can go from -24 to +24 degrees in steps of 2 degrees. Remember to check each position is above the horizon!

This can be achieved by working as a group and sharing results or you can obtain all your own data. You will also find suitable observations in the *Archive*. You can of course repeat an observation if you feel something has gone wrong - perhaps an interference spike is present (note interference may be present when the telescope is pointing in a particular direction). [Note the source velocity should be set to 0 km/s in all cases].

3.1 Results/Analysis

If you plot the spectra versus velocity then the area underneath the emission line profile on your graphs will be in units of Kelvin times km/s and is proportional to the amount of hydrogen along the line of sight. Note when calculating the area you need to estimate the background level underneath the main peak by connecting the background either side with a sloping line. This can be done by

clicking on the background either side of the emission peak in the Java applet which plots the spectrum. Alternatively the data files can be obtained from the computer and analyzed later on a computer using your own software e.g. Excel.

Plot a graph of the area under your spectra (the amount of hydrogen in that direction) versus galactic latitude (all spectra should be at the same 120-degree longitude). What is the angular width of the galactic disc at half the peak level?

The picture below illustrates the general idea with the disc of hydrogen represented by the rectangle. A line of sight from the Sun (the small circle at the centre) along a particular galactic latitude (the angle indicated by an arc) is shown by an arrow. Clearly as you go to higher galactic latitudes you are looking out of the plane and through less and less hydrogen.
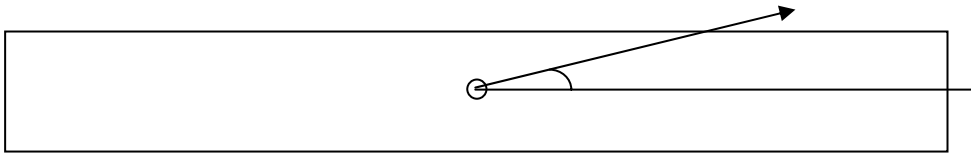
You should also describe and explain how the structure of your spectra change with latitude.