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## JODRELL BANK OBSERVATORY 7-M RADIO TELESCOPE

### EXERCISE 2: HI EMISSION FROM THE DISC OF THE MILKY WAY GALAXY

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#### Exercise 2: Aim

In this experiment you will take a spectrum of HI from the Milky Way Galaxy. In particular, you will make observations that will support the existence of spiral arms and determine the velocity of HI peaks corresponding to emission from those spiral arms.

#### Introduction

Due to the rotation of our Milky Way galaxy, along any given line of sight different regions of hydrogen gas we observe will be moving with different velocities with respect to us. Therefore, the emission from hydrogen which is generated at 1420.406 MHz is actually observed at a range of frequencies due to Doppler shift. This produces a profile in the spectrum which varies in appearance for different regions of the galaxy. To measure these HI (neutral atomic hydrogen – pronounced “H-one”) profiles, we pass the signals into a high-speed digital sampler from which we can use a Fourier transform technique to obtain a spectrum of the radio emission. Don't worry if you don't understand what a Fourier transform is – it's basically a way of getting information on the different frequencies present in a signal by sampling the signal strength at a very high rate.

When plotting spectra, it is convenient to work in temperature on the y-axis and frequency or 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), the 5 MHz bandwidth of the 6.4m telescope receiver 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 (the background noise level due to the receiver) which has a curved shape. We require some way of subtracting this, leaving just the spectra. One way of doing this would be to point the telescope at the target of interest, collect the signal for a while (called integration) then move a few degrees off to one side to obtain a spectrum of a reference position, and then subtract the two spectra. Whilst this *position switching* method is fine for observations of objects outside our own galaxy, when looking at HI in our galaxy there is virtually no clear part of the sky. In this case, we obtain a reference spectrum by changing the observing frequency whilst pointing at the same position. Such a *frequency switching* mode can be achieved by changing the frequency of the local oscillator (signal generator). 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.

#### A Spectrum from Galactic Position (120, 0)

For your first observation of HI in the Milky Way Galaxy we will select a position in the galactic plane that is visible all the time from Jodrell Bank Observatory (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.

You will now need to check using [Show Queue](#) what observing 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 minutes on source plus 2 minutes on reference plus about 1 minute 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). Select a slot a few minutes ahead at least, to give time for you to confirm it (see below) and for the software to insert the observation into the telescope queue.

In the [Setup Obs](#) section (after supplying your username and password if required) select the first option – a simple 21cm spectral line observation. On the web form, input your username again and, if you wish, a password to identify your observations. Set the galactic longitude and latitude to be (120, 0) and the integration time to be 120 seconds. The system automatically sets up a frequency-switched observation with a default -3 MHz offset. Set the slot in which you wish the observation to take place. Remember the time is in Universal Time. Select ‘1’ for the number of slots required. Click on [Submit](#) to add the observation to the queue. Once you have inserted your observation in the queue check the details from the [Show Queue](#) page. Your observation will appear at status 0 with an exclamation mark next to it. If you're happy, click on the [Submit](#) link on the [Show Queue](#) page. 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 **Show Queue** screen to check if the status has changed).

You should be able to use the **Monitor**, **Skymap** and **Webcam** to watch the telescope move and your observation take place (status will be 3 in the list while the observation is running) and when it is completed the status should change to 4 and the data should then be available for viewing. Note that for the spectrum observation, the telescope first integrates on the target position, then integrates at the same position with the frequency offset added. When the observation completes, it is moved from the Queue list to the Archive list under Recent Observations – click on **Show Archive** to show the data and click on the **Data** link to see your spectrum.

## Measurements & Analysis

The HI line profile should show a curved background level with a large peak of emission due to hydrogen around a frequency of 1420.4 MHz. This peak should show some structure due to Doppler shifts of hydrogen in several spiral arms along that line of sight through the galaxy. We can measure the velocities of each of the spiral arms visible in your spectra. There should be three clear peaks in the hydrogen line corresponding to three spiral arms. For the purposes of this project it will be sufficient to simply measure the positions of the peaks by zooming in and noting the velocity value at the highest point of the peak.

On the data plot you can choose whether to plot 'Frequency' or 'Velocity' along the horizontal axis in the pull-down menu. You can also carry out a temperature integral by clicking to the left of the emission line and then to the right - a line is drawn and the emission above this is integrated. This can be done on either the frequency or velocity plot; the units of the integral whose value is displayed in the third box are then K MHz or K km/s respectively. The values of the start and end point of the integral on the horizontal axis are also shown in the first two boxes. You can also click on the graph and drag out a box to zoom into any region. Click on the 'Fill' button to zoom back out. To measure the velocities of three peaks, display the spectrum with velocity as the horizontal axis then zoom in to the region near the top of one of the peaks by clicking at the top left of a small rectangle centred on the peak and then dragging to the bottom right of a rectangle. Estimate the velocities of all three peaks by eye, noting that the labelling on the axis may need to be multiplied by 100 to get the actual velocity in km/s.

You should find the velocities are about -100, -55 and 0 km/s (with a little shoulder at around -10 km/s). Look at the schematic picture of the spiral arm structure of the Milky Way in Figure 1 (left) and work out which spiral arm corresponds to which peak in your spectrum. Note that because the galactic disc does not rotate as a solid body (in fact many parts of the disc rotate at almost the same velocity) this means that the Sun is overtaking the stars and gas which are farther away from the centre of the Galaxy than itself i.e. we are 'overtaking on the inside'. Hence when viewing at a longitude of 120 degrees we are looking at hydrogen gas which we are approaching and hence the Doppler-shifted velocities are negative! Furthermore, if we assume that all the material in the disc is actually moving at the same speed in a circle then the component of velocity along the line of sight is smaller for the gas which is farther away. 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 in Figure 1. This relative velocity is therefore larger for the clouds of gas which are farther away in this direction. You should therefore be able to conclude that the peak at -100 km/s is due to the Outer Arm, the one at -55 km/s the Perseus Arm and the one at 0 km/s to hydrogen in our Local Arm which is moving with the Sun.

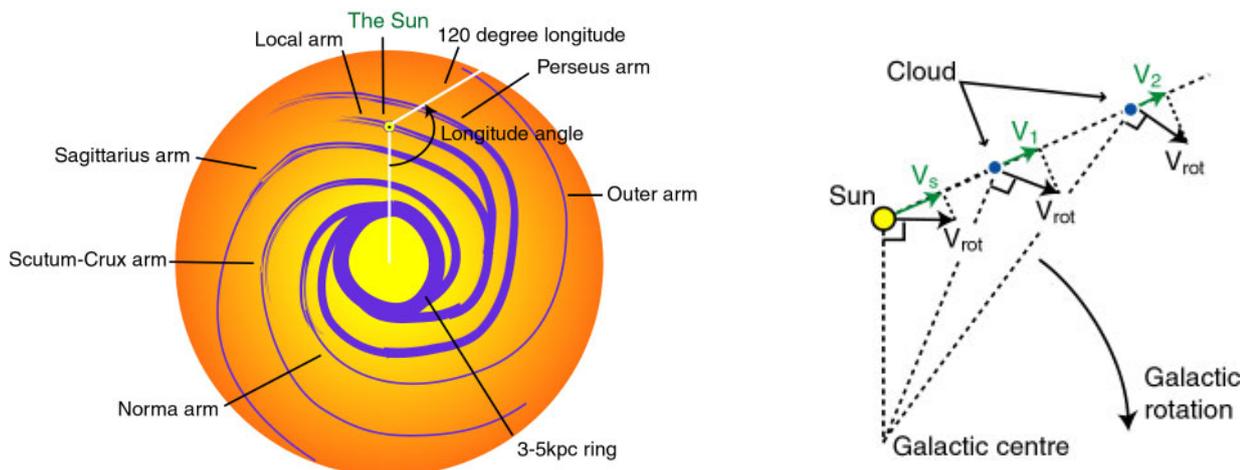


Figure 1: A schematic representation of the spiral structure of the Milky Way Galaxy and the components of velocity