Velocity Curve Activity Part 1: Quadrants II & III Observation & Analysis

TEACHER NOTES

Level: *HS Advanced, College*

Objective: *In this activity, the students will take measurements of HI spectra along the galactic plane in the quadrants II and III to find evidence that the Milky Way Galaxy rotates.*

Pre-Knowledge of Students:

- *The students have been exposed to the horn telescope and understand how to read a spectrum.*
- *The students understand what radio waves are, and they understand that the spin-flip in hydrogen atoms is the source of the 21-cm waves detected by the horn telescope.*
- *The students understand how to apply the Doppler shift to the spectrum peaks in order to find the relative velocity of the detected hydrogen.*
- *The students understand relative velocity.*

Key Terms: *horn telescope, HI spectrum, galactic coordinates, Horizontal Coordinates, Stellarium, Doppler Shift, red shift, blue shift, relative velocity*

Related Videos for Teacher: "Galaxy Survey Trailer," (https://youtu.be/tDCPGalaxy Survey Trailerp8RIM4g)

Teacher Preparation:

- *This activity can be done with a single horn shared with the class, or with multiple horns assigned to groups of students.*
- *The students have used a horn telescope before. It is recommended that the following lessons have been completed:*
  - *Intro to the Horn Telescope*
  - *Electromagnetic Spectrum*
  - *The 21 cm Wavelength of Neutral Hydrogen*
  - *Understanding Coordinate Systems*
- *The teacher should be familiar with the implications of red shifted and blue shifted signals, and understand that the general trend of blue shifted peaks from quadrant II and red shifted peaks from quadrant III imply that the galaxy rotates in a CW sense in reference to standard galactic coordinates.*
- *The* "Galaxy Survey Trailer" *video* (https://youtu.be/tDCPp8RIM4g) *illustrates the results of scanning quadrants II & III. If you look at the graphs in that video, you can see the galactic longitudes range from 90º to 240º. The vertical red line on the graph is at the unshifted hydrogen frequency of 1420.41 MHz. You can see how the peak positions are red shifted for galactic longitudes from 240º to 180º (quadrant III), and are blue shifted for galactic longitudes from 180º to 90º (quadrant II). This implies that we are moving away from the hydrogen in quadrant III and toward that in quadrant II, which is counterclockwise in the galactic coordinate system.*

Activity Notes:

- *Break the class into groups of two.*
- *Assign each pair one or two galactic coordinates from ℓ = 90º to ℓ = 230º in increments of 10º or 15º. [ℓ is the standard symbol for galactic longitude.]*
- *Use Stellarium to find dates when this part of the galactic plane is visible from your observation site.*
- *Plan ahead so that you can have the telescope set up and ready when class time begins.*
- *Calibration of the telescope is not necessary. The peak positions will be accurate without calibration.*
- *An integration time of 10 s should work fine.*
- *The Capture Current Spectrum button in the spectrometer is used to save each spectrum to the specified folder.*
- *Use the azimuth and elevation text boxes on the spectrometer screen to record each group's coordinates. These will show up in the data file names and will make data identification easier after the observation.*

Data Analysis Notes:

- *If the students scale the frequency range on their graphs from 1419.5 to 1420.5 MHz. Scale with major gridlines at each 0.1 MHz and a minor gridline count of 10 for 0.01 MHz intervals. *
- *The students should be able to read accurate peak positions, to a precision of 0.01 MHz, directly from the graph.*
- *Students use the relative velocity equation to calculate the velocities indicated by their peaks:*

$$v = \frac{(1420.41\ MHz - f_{peak})}{1420.41\ MHz} \times 3.00 \times 10^5\ km/s$$

- *Positive velocities are red-shifted, where the object is moving away from us, and blue-shifted velocities are negative.*
- *Have each student/group share their results with the class in a table similar to the one below.*

Galactic Longitude	***Quadrant***	***Velocity (km/s)***	***Uncertainty (km/s)***	***Red or Blue shift?***

- *Most of the quadrant II peaks should be blue-shifted, and most of the quadrant III should be red-shifted. This implies that the earth/sun is moving away from quadrant III and toward quadrant II.*
- ***Important:** Depending on the time of year this activity is done, the quadrant II peaks may not all be blue-shifted, and the quadrant III may not all be red-shifted. This is due to the earth's relative motion around the sun, which contributes to the relative velocity detected and can be as much as ±29 km/s.*

- *Because quadrants II and III are farther from the galactic center than us (the sun), these results suggest that the galaxy is rotating, with the inner portion (us) spinning faster than the outer portion (the observed hydrogen).*
- *Note that these results are consistent with the known velocity curve that shows that the Milky Way Galaxy has a mostly flat (constant) velocity curve. Parts of the galaxy at different distances from the center have the same speed, and so a point that is closer to the center has a faster angular velocity than those farther out, according to* $\omega = \frac{v}{r}$*, where v = constant (approximately) for all distances from the GC.*
- *Student Conclusions:*
  - *Have each group present their results.*
  - *After the results are presented and the table completed, have each group describe their conclusions on a whiteboard.*
  - *Discussion: try to get the students to conclude that the blue shifts of the Quadrant II peaks and the red shifts of Quadrant III peaks implies a rotation that is clockwise in the standard galactic coordinate system.*