Detecting Galactic Hydrogen using GNU radio and ATA

Concepts and skills:

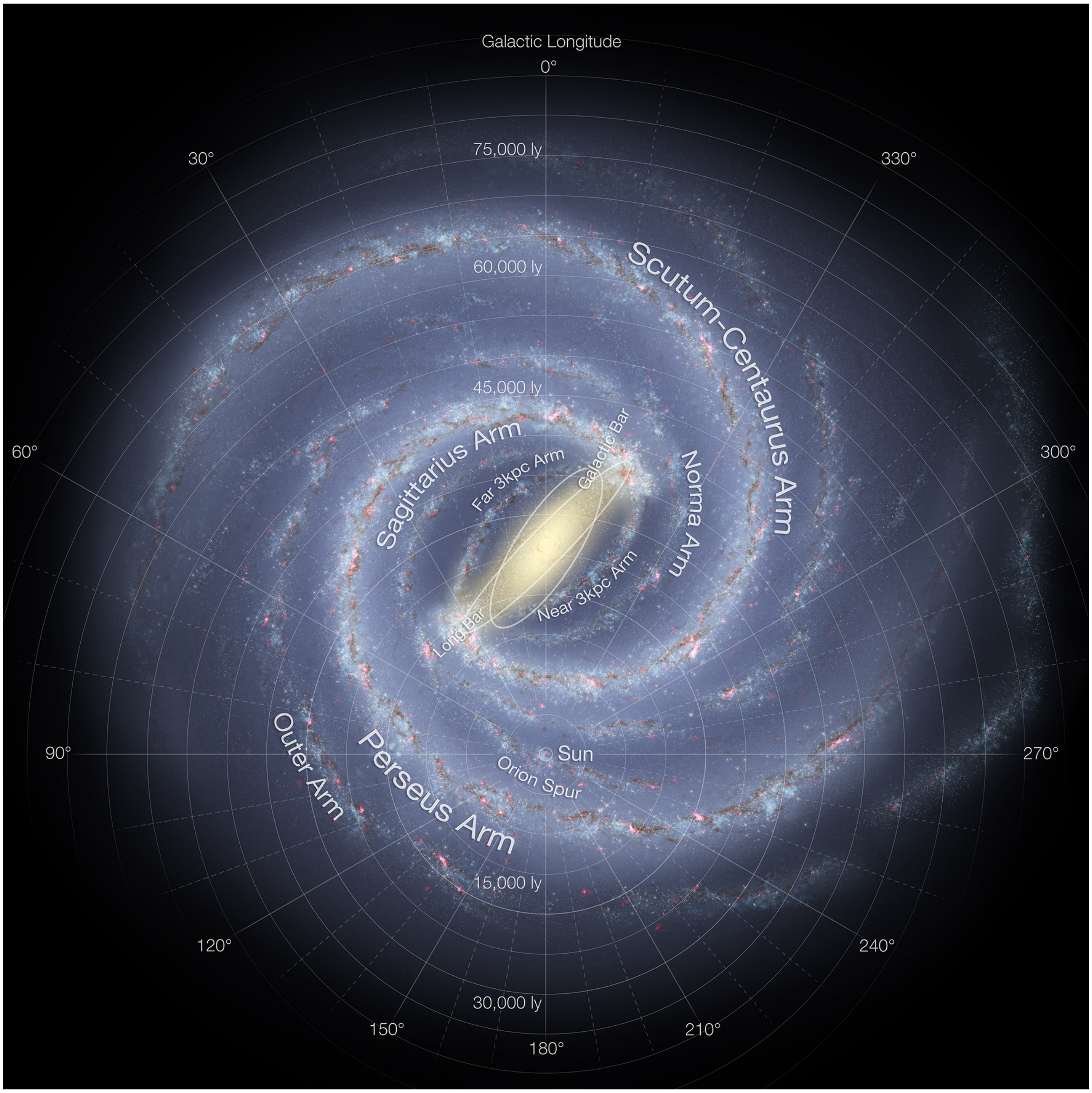
1. Concept: If a transmitter of light or sound is approaching/receding, its wavelength will be shorter/longer (Doppler shift)
2. Concept: You can use Doppler shift to get velocity
3. Concept: Hydrogen gas at rest emits radio waves, and we can use this to map the galaxy
4. Concept: We live in a spiral galaxy
5. Skill: Given the rest wavelength of a line and its shift, calculate the relative velocity

Duration: This learning plan is designed for a 2-hour lab course

STEPS TO FOLLOW

1. Introduction to the Milky Way and Radio Astronomy:
   1. Basic structure of the Milky Way, highlighting its spiral nature, the distribution of gas, stars, and other components.
   2. Principles of radio astronomy, focusing on the significance of the hydrogen line in understanding galactic structures.
2. Introduction of GNU radio equipment and the ATA which will be used in collecting data for the lab
3. Data Collection:
   1. Direct two of the ATA antenna towards two different galactic coordinates.
   2. Start the GNU-radio backend and observe hydrogen lines overlaid from two different galactic coordinates.
4. Analysis of Doppler Velocities:
   1. Once the data is collected, measure the observed hydrogen line frequency and compare them for two directions.
   2. Convert observed frequency to velocity using Doppler shift formula.
   3. Discuss how these velocities can provide insights into the rotational dynamics of the galaxy and identify potential gaps or anomalies in the gas distribution.
   1. Conclude by reinforcing the understanding that these findings highlight our position within the spiral arms and the dynamic nature of our galaxy.1

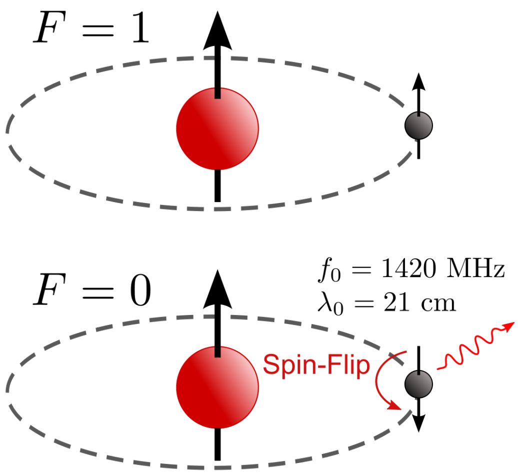
1. Milky Way Galaxy



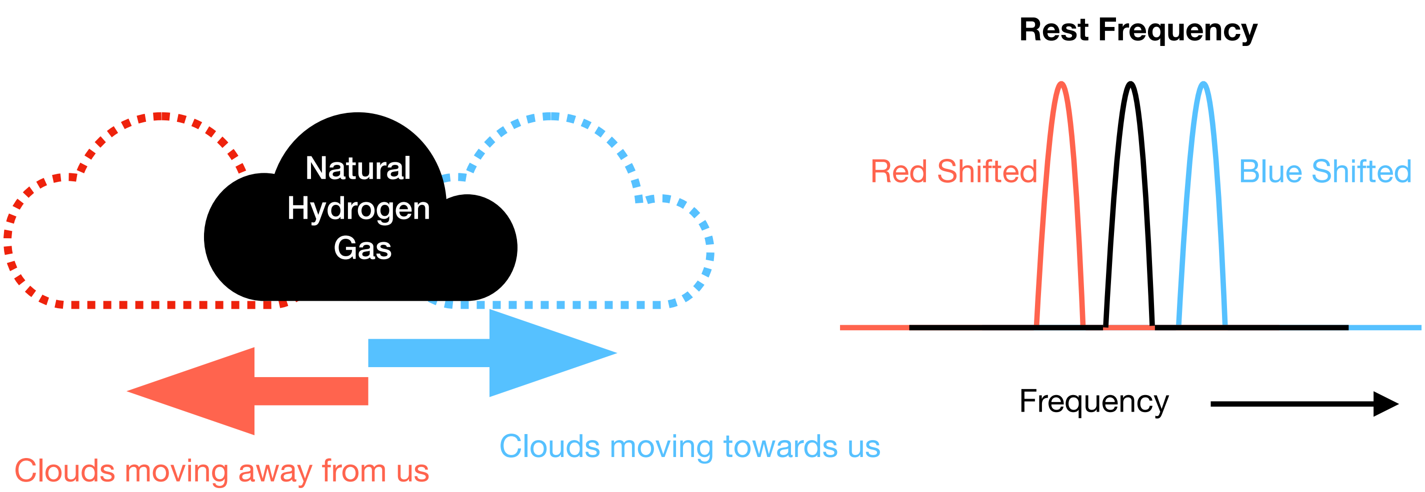
The Milky Way galaxy, with concentric circles indicating distance in light-years from the galactic center. Highlighted are the prominent spiral arms rich in hydrogen gas. It's this hydrogen, primarily in its neutral atomic form (HI), that emits the radio wave at 1420 MHz, a key spectral line used in radio astronomy to study galactic dynamics and composition.

Further Reading: https://universe.nasa.gov/galaxies/basics/

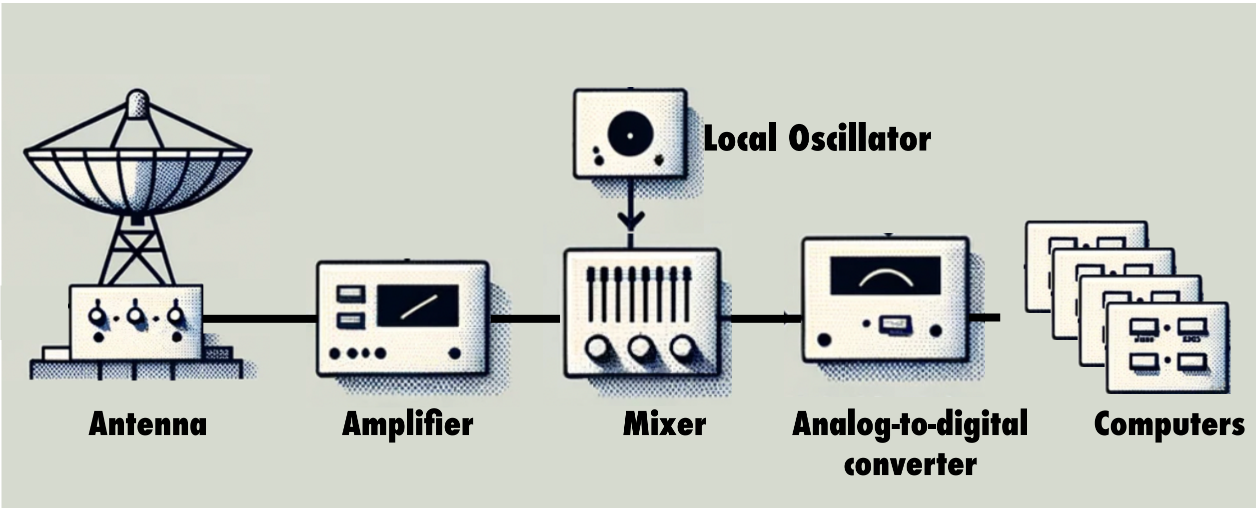
2. Hydrogen Line



In neutral hydrogen atoms, the electron and proton can have parallel or anti-parallel spins. The 21-cm line is produced when the electron's spin direction flips from being parallel to the proton's spin to being anti-parallel. This spin-flip transition leads to the emission of a photon with a wavelength of 21cm, which corresponds to a frequency of 1.42 GHz. This transition is extremely rare (11 million years) but the excess of hydrogen gas in the Milky Way galaxy will give rise to a prominent line. As this hydrogen gas moves around, this line shifts in frequency due to Doppler effect.



Further Reading: http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/h21.html



3. How do we capture radio waves from space?

Schematic of a typical radio telescope signal capture pipeline

A radio telescope converts electromagnetic waves from space into electrical signals. These signals, often faint due to the vast distances they travel, are then passed through an amplifier, which boosts their strength for further processing. The enhanced signals are subsequently directed to a mixer, where they are combined with a signal from a local oscillator. This process shifts the signals to a lower frequency range, making them easier to analyze. From the mixer, the signals are then funneled to an analog-to-digital converter, which transforms the analog signals into a digital format suitable for computer processing. Finally, the digitized signals are fed into computers, where sophisticated software algorithms analyze and interpret the data, enabling astronomers to draw insights about distant celestial bodies and phenomena.

Further Reading: https://public.nrao.edu/telescopes/radio-telescopes/

4. Allen Telescope Array (ATA)

Situated in the landscapes of northern California, the Allen Telescope Array (ATA) boasts 42 coordinated antennas, each with a 6-meter diameter, primarily designed for the Search for Extraterrestrial Intelligence (SETI). These antennas can be directed towards any target of interest using their azimuth and elevation motors.

We will be using two of these 42-antenna today to detect hydrogen gas from Milky

Way galaxy.
Further Reading: https://www.seti.org/ata