Galactic Structure Mapping through 21cm Hyperfine Hydrogen Transition Line

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Using a Small Radio Telescope (SRT), we measure electromagnetic radiation centered around 1420.4 MHz. This frequency corresponds to the hyperfine transition line in the hydrogen atom - a process so strongly forbidden that the only detectable sources of this transition are due to large galactic formations of hydrogen. By analyzing the Doppler shift in this 1420.4 MHz emission, we are able to determine the velocity of sections of the Milky Way galaxy. Futher geometric considerations allow us to determine the location of these high-density hydrogen structures, confirming a spiral-arm strucutre of the Milky Way galaxy.

I. INTRODUCTION

In 1944, Hendrick van de Hulst predicted an emission of 1420.4 MHz radiation from neutral hydrogen from a hyperfine splitting transition (detailed further in Section II). As electromagnetic energy in this range can pass through Earth's atmosphere easily, this discovery proved to be immensely useful in the field of astronomy. Soon after this discovery, Edward Purcell and Harold Ewen published a paper detailing their successful detection of this emission line through a radiometer. This emission line was used to determine the spiral structure of our Milky Way, as well as information about other galaxies. In this paper, we reconstuct some of the key features of the Milky Way's spiral arm structure using radio astronomy.

II. THEORETICAL BACKGROUND

Due to the low temperatures predominant in interstellar medium, hydrogen is most often found in its ground state. Due to the magnetic moments from the spins of both the proton and the electron, the hydrogen ground state has two modes - one where the two spins are aligned, and one where the spins oppose each other. The former has slightly higher energy, and when a hydrogen atom transitions from both spins being aligned to being disaligned, it emits radiation with a wavelength of 21cm, or with a frequency of 1420.4 MHz. This process is highly unlikely, occurring at a transition rate of $2.9 \times 10^{-15}\ s^{-1}$. However, in large enough quantities, this process produces radiation at a constant frequency, which can be observed by a radio telescope.

Because of the dynamic nature of our galaxy, hydrogen that we observe can be moving relative to us. This relative motion has a Doppler effect on the radiation frequency observed. The relationship between a body moving away from the Sun at a relative velocity V and the frequency f that we observe is given by

$$V = \frac{(1420.406 - f)c}{1420.406} - V_{lsr} \tag{1}$$

Where c is the speed of light and V_{lsr} corrects for the motion of the Earth around the Sun. The purpose of considering relative motion away from the Sun as opposed to the Earth is for the sake of geomoetric simplification.

Given this information, we can calculate the location of the hydrogen source through geometric considerations. Illustrated in Figure 1 is the relevant geometry of our galaxy. The velocity due to Doppler shifting is given by the *actual* velocity of the hydrogen mass Θ projected along the line of sight from the sun, minues the sun's velocity projected along the lihe of sight. Through the law of sines, we can calculate the general relation

$$V = \frac{\Theta}{r} R_0 \sin \ell - \Theta_0 \sin \ell \tag{2}$$

Where R_0 and r are the distances from the sun and our hydrogen mass to the center of the galaxy, Θ_0 is the velocity of the sun, and ℓ is our viewing angle. Both r and Θ are unknown, but a general relation between the radius of an object from the center of the galaxy and its velocity can be determined via the Galactic Rotation Curve. This gives an equation that allows us to calculate r given the viewing angle ℓ and our observed velocity V. We restrict our viewing angle to $90 \leq \ell \leq 180$. In this regime, the Galactic Rotation Curve predicts Θ to be approximately constant at 200 km/s, which greatly simplifies calculations.

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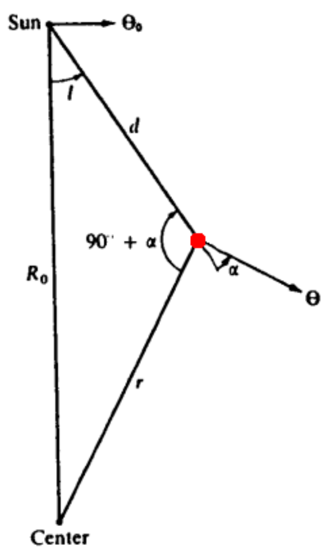

FIG. 1. The relevant geometry of our galaxy. Known constants are the distance from our sun to the center of the galaxy,$R_0 = 8.2 \pm 0.5$, and the velocity of our sun. $\Theta_0 = 223 \pm 17$. The viewing angle ℓ is determined by the posiiton of our telescope.