H21

The Hydrogen 21-cm line is a significant tool in radio astrophysics, offering unique insights into the universe that are not accessible through optical light.

- The 21-cm line is **emitted by neutral hydrogen (H1) atoms**
- A neutral hydrogen atom consists of one proton and one electron, both possessing a quantised total spin of 1/2.
- What was once considered a degeneracy in the hydrogen atom's ground state is, in fact, a very fine energy level split. This split occurs between a **more energetic parallel spin state** (where electron and proton spins are aligned) and a **less energetic anti-parallel ground state** (where spins are anti-aligned).
- When a hydrogen atom transitions from the excited, parallel spin state to the ground, anti-parallel spin state, it emits a photon. This photon has a **wavelength of 21 cm**.
- This transition is known as a **spin-flip transition**
- frequency : **1420.4 MHz**

Due to the long mean-life of the spin-flip transition, the Heisenberg Uncertainty relationship suggests a **very sharp emission line with small energy dispersion (line width)** in frequency.

Its long wavelength (radio wave) allows it to **reach us from parts of deep space that optical light cannot penetrate**. This is because attenuation through a given material decreases as the wavelength of light increases. Interstellar gas clouds, which would obscure optical features, reveal galactic structure and dynamics when observed at this wavelength.

APPLICATIONS:

The 21 cm hydrogen line is widely used in radio astrophysics for **spectroscopic velocity measurements** due to its extremely sharp and well-defined nature. Even small **Doppler shifts** in its frequency can be precisely detected, allowing astronomers to measure the **radial velocity** of hydrogen gas in galaxies. Using the **relativistic Doppler formula**, the observed shift in frequency can be converted into the **velocity** of the source, whether it's moving toward or away from us. This technique is essential for **mapping galactic rotation curves**, analyzing **gas motions**, studying the **expansion of the universe**, and providing indirect evidence for **dark matter** through deviations in expected velocities.

The 21 cm hydrogen line plays a crucial role in **exploring galactic structure and dynamics**, particularly in constructing the **Milky Way's rotation curve**. By measuring the **Doppler-shifted 21 cm spectra** at different galactic longitudes, astronomers can determine the **rotational velocity vvv** of neutral hydrogen gas at various **galactocentric radii rrr**. These observations reveal that the Milky Way's rotation curve does **not follow Keplerian predictions**, which would expect velocity to decrease at large radii. Instead, the curve rises

roughly linearly from $r = 0$ to about **2.5 kpc**, and then remains **nearly flat** out to and beyond the Sun's orbital radius $R_{\odot}$. This flat rotation curve is strong evidence for the presence of **dark matter**, as visible matter alone cannot account for the constant orbital speed at large distances from the galactic center.
The **flatness of the Milky Way's rotation curve** at large radii provides strong **evidence for dark matter**. According to Newtonian gravity, if only visible matter were present, the rotational velocity should decrease with distance from the galactic center — a **Keplerian decline**. However, observations show that the velocity remains roughly **constant beyond** $R > 2.5\,kpc$**. This discrepancy suggests the presence of an unseen, extended** dark matter halo **surrounding the galaxy. If this halo has a** mass density that falls off as $1/r^2$, it would produce the **flat rotation curve** observed, thereby explaining the otherwise unexpected galactic dynamics.
The **21 cm line** also provides insight into the **spiral structure** of the Milky Way. By analyzing the **relative intensities at different redshifts** in the 21-cm spectra, astronomers can identify regions of **high neutral hydrogen concentration**. Mapping the locations of these intensity peaks across different **galactic longitudes** reveals the presence of **spiral arms**. For instance, observations between **30° and 80°** in galactic longitude have shown two distinct **density waves**, likely corresponding to the **Orion Arm**—where our solar system is located—and a portion of the **Sagittarius Arm**. These findings support the view that the Milky Way has a **spiral arm structure** traced by neutral hydrogen gas.

21 cm observations of the Sun indicate a chromospheric temperature of ~35,000 K, much higher than the surface, confirming the emission originates from the Sun's hotter chromosphere.

The **21 cm line** can be used to estimate the **angular extent** of emission from the **galactic plane**. For instance, observations near **galactic longitude 30°** showed a bulk emission region about $(2.7 \pm 0.2)^{\circ}$ wide.

21 cm observations are typically carried out using **radio telescopes**, like the **Small Radio Telescope**, which convert incoming signals into frequency spectra via **Fourier transforms**. Accurate measurements require **calibration**, including **temperature calibration** using a noise diode to relate signal power to effective temperature. Additional corrections—such as for **pointing errors**, **velocity dispersion** of gas, and the **observer's motion relative to the galactic center** (VLSR correction)—are essential for reliable results. However, observations often face **challenges from radio interference**, including signals from **cell towers**, **phones**, and **satellites**, which introduce **noise** and distort the spectra, especially at **lower galactic longitudes**.