21cm Transition

From AstroBaki
Jump to navigationJump to search

Course Home

Short Topical Videos

- Basics of the 21cm Hyperfine transition (by Dyas Utomo) (http://www.youtube.com/watch?v=yZYpEtF2H-k)

Reference Materials

- The HI 21-cm Line (Condon & Ransom, NRAO) (http://www.cv.nrao.edu/course/astr534/HILine.html)

Need to Review?

- Einstein Coefficients
- Boltzmann distribution
- A Review of Equilibria (https://www.youtube.com/watch?v=B_TwNUjcoh8&feature=youtu.be)

Contents

Hyperfine transition of hydrogen atoms

The ground state of atomic hydrogen split into two hyperfine levels by the interactions between the spins of electron and proton. Parallel spin has higher energy than antiparallel spin. The energy difference between these two levels is $6 \times 10^{-6} eV$ which corresponds with photons with frequency $\nu =$ 1.4204 GHz or wavelength 21.105 cm.

Einstein coefficient

The Einstein coefficient A_{21} is the probability for a system in the excited level E_2 to return spontaneously to the lower level E_1. Therefore, if N_2 is the electron density in level E_2 then $N_2 A_{21}$ is the number of such spontaneous transition per second per unit volume.

The probability that incoming photon is absorbed is $B_{12}U$ where $U = 4\pi I/c$ is the average energy density of the radiation field. So, the number of photons absorbed by electron in level E_1 to jump to E_2 is $N_1 B_{12} U$. There is another emission process proportional to U that need to include: $N_2 B_{21} U$ which equal to the number of photons emitted by ”stimulated emission”.

For system in stationary state, the number of absorbed and emitted photons must be equal, so

$$N_2A_{21} + N_2B_{21}U = N_1B_{12}U$$

For hyperfine transition,

$$A_{10} = 2.86888(7) \times 10^{-15}s^{-1}$$

.

This transition probability is about 10^{23} smaller than that of an allowed optical transition.

Characteristic time for hyperfine transition is

$$t_{1/2} \approx 1/A_{10} = 3.49 \times 10^{14}s \approx 1.11 \times 10^{7}yr$$

.

Spin temperature

Spin temperature T_s describes the ratio of atoms in the excited states (N_1) to the ground state (N_0). According to Boltzmann distribution:

$$\frac{N_1}{N_0} = \frac{g_1}{g_0}\exp(-\frac{h\nu}{kT_s})$$

There are three processes which determine the population of the hyperfine levels in ground state of hydrogen: collisions, 21 cm radiation, and Lyman-α radiation. Their relationship with spin temperature is

$$T_s = \frac{T_R + y_cT_K + y_LT_L}{1 + y_c + y_L}$$

where T_R, T_K, and T_L is the brightness temperature of 21 cm radiation, kinetic temperature, and the temperature of Lyman-α, respectively, while y_c and y_L are coefficients which determine the relative efficiencies of the processes.

Spin temperature becomes equal to thermal temperature after many interactions between atoms via collisions or radiative transfer.

HI Column Density

HI column density N_H is the number of neutral hydrogen atoms per unit area of line of sight. If the spin temperature T_s is constant along the line of sight then

$$N_H = 1.8224(3) \times 10^{18}(\frac{T_s}{K})\int \tau(v)d(\frac{v}{kms^{-1}})cm^{-2}$$

If the line is gaussian then this approximation is useful:

$$N_H \approx 1.94 \times 10^{18}(\frac{T_s}{K})\tau_0(\frac{\Delta V}{kms^{-1}})cm^{-2}$$

where τ_0 is the Gaussian peak and ΔV is the Full Width Half Maximum (FWHM) of the Gaussian.