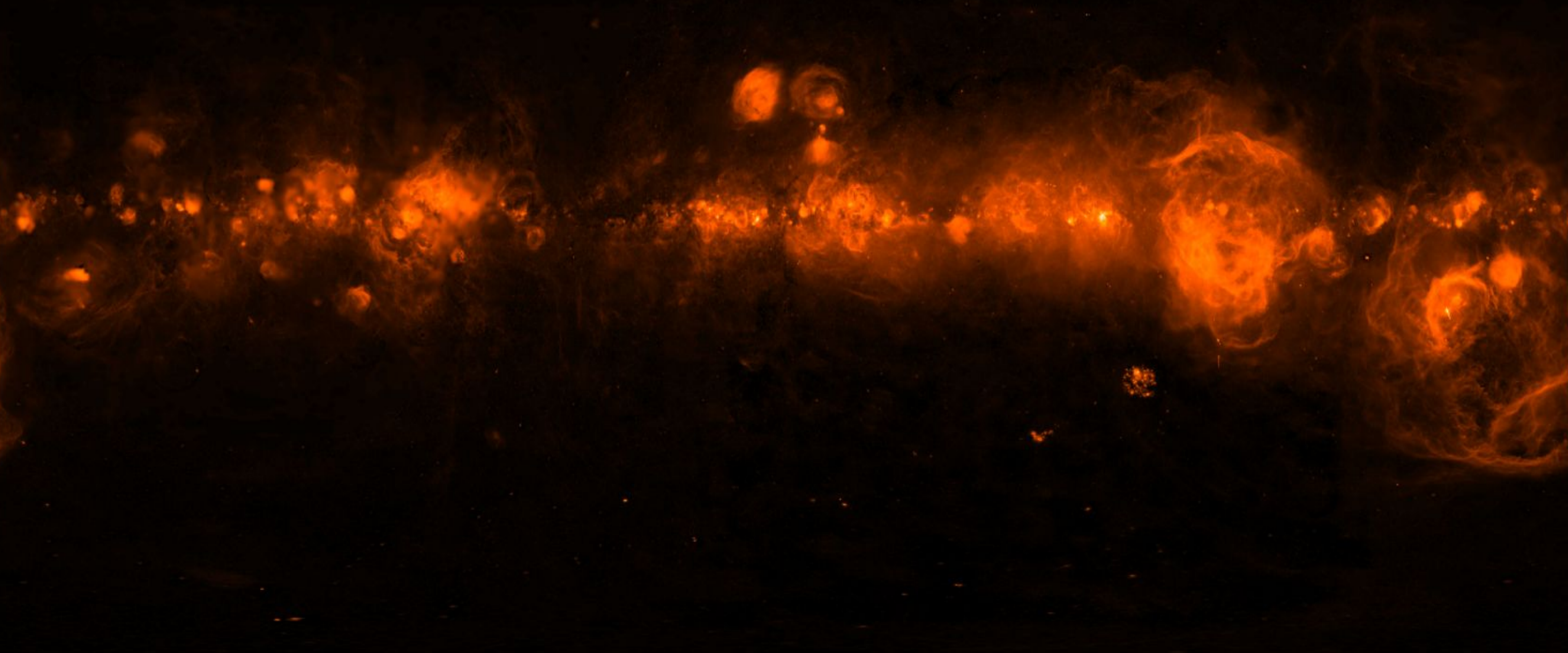
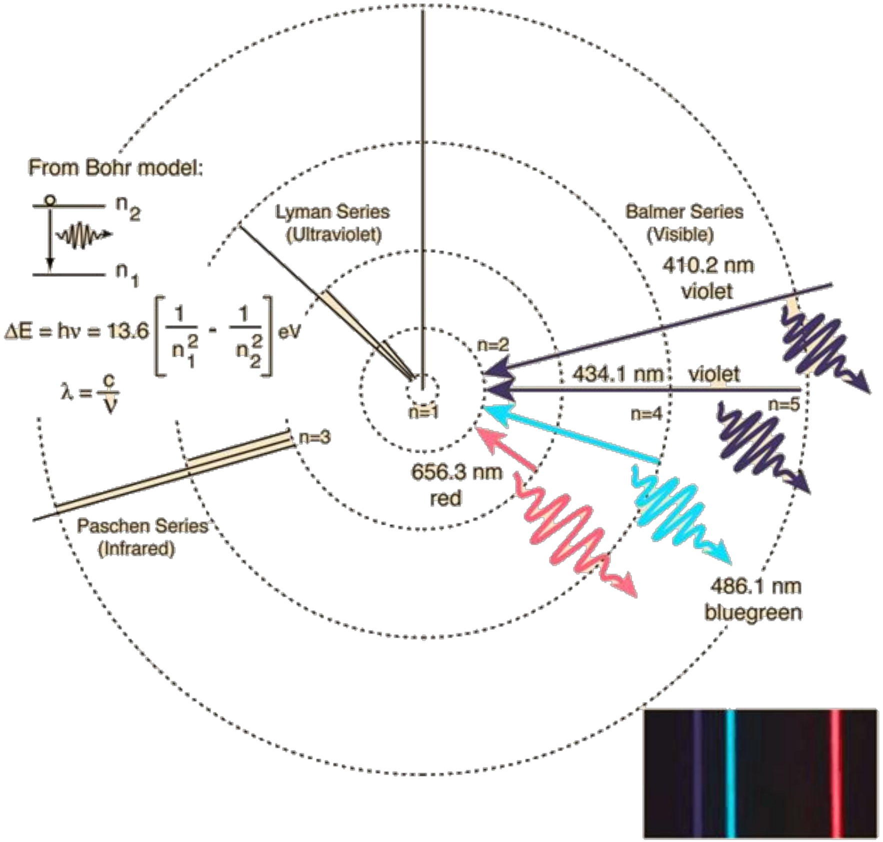
The HI Line

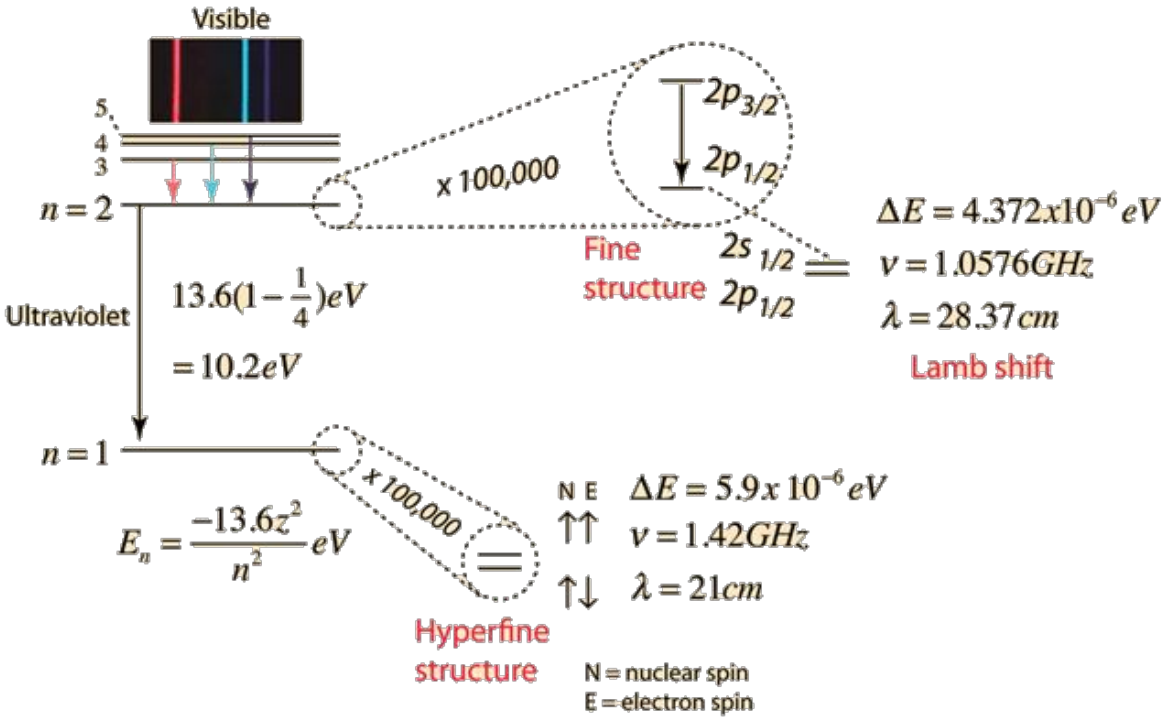


The Bohr Model - A Recap



- Electrons orbit the nucleus of an atom in quantized energy levels
- The transition of an electron from a higher to lower energy level causes the emission of a photon

HI Hyperfine Splitting



- The relative spin of protons and electrons are quantized
- In HI, the magnetic interaction between the spin of the proton and electron causes a splitting of the energy level into two hyperfine states
  - Parallel: Spins are the same direction
  - Antiparallel: Spins are opposite direction
- The flip from parallel to antiparallel in the 1s level causes the emission of a photon of wavelength 21 cm.

Emission Rate and Half-life

$$A_{UL} = \frac{64\pi^2}{3hc^2}\nu_{UL}^2|\mu_\beta|^2$$

Emission rate: 2.85×10^{-15} s^{-1}

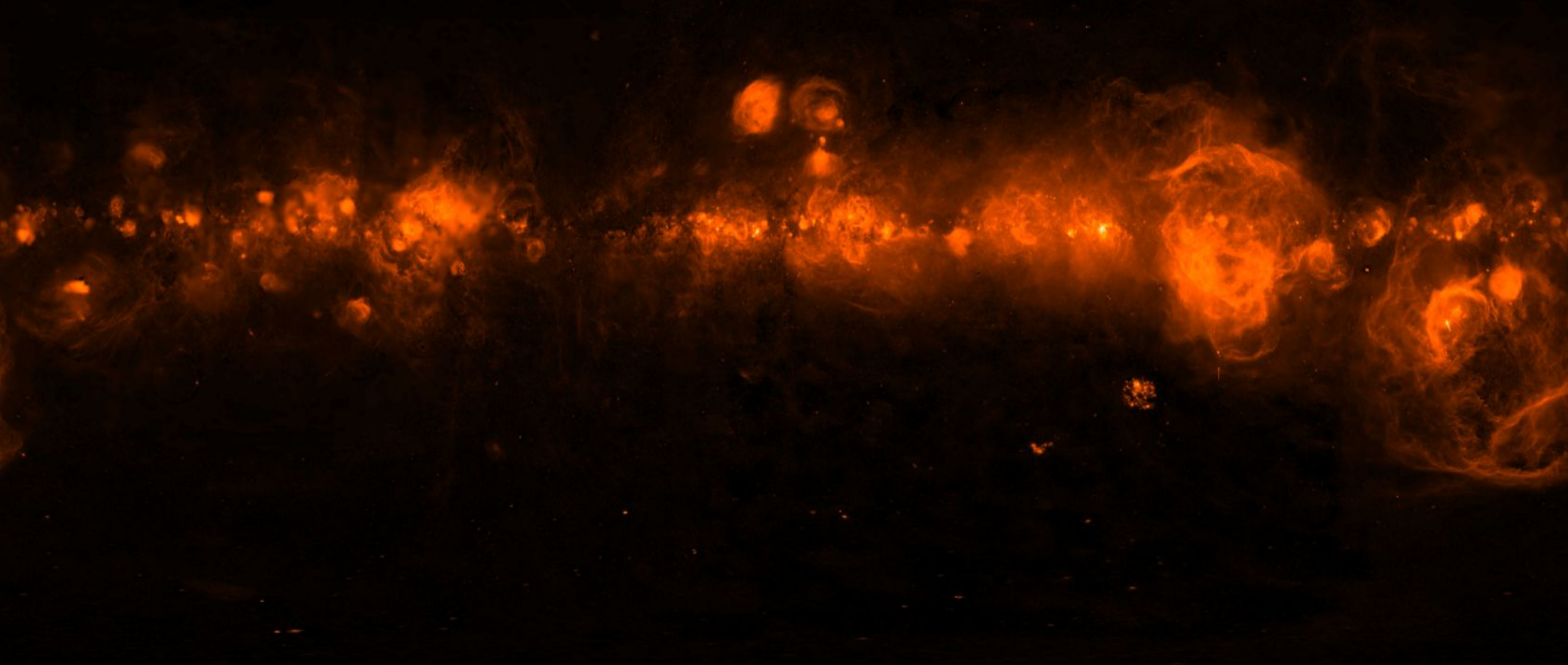
Frequency of HI line emission: 1420.405751 MHz

Bohr Magneton: The magnitude of the mean magnetic dipole moment 9.27×10^{-21} ergs/gauss

Q: What is the radiative half-life of HI emission?

Q: If the emission rate is so tiny, why is HI so prominent?

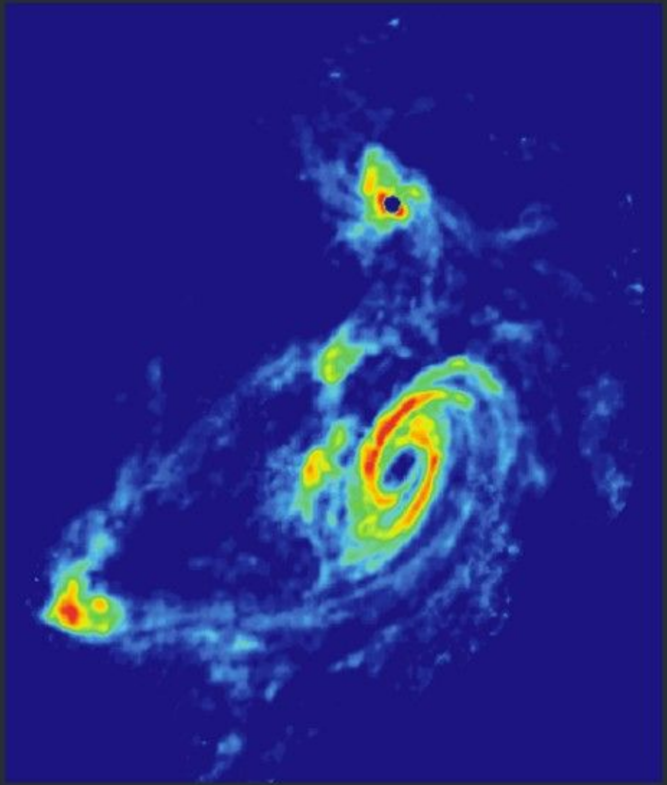
Because it’s everywhere!



TIDAL INTERACTIONS IN M81 GROUP

Stellar Light Distribution

21 cm HI Distribution



Boltzmann Equation

$$\frac{N_u}{N_L} = \frac{g_u}{g_L} \exp \frac{-\Delta E}{kT_s}$$

- N_U: Number density of HI atoms in parallel state
- N_L: Number density of HI atoms in anti-parallel state
- g_U= 3: statistical weight of HI in parallel state
- g_L= 1: statistical weight of HI in anti-parallel state
- T_S: Spin temperature or excitation temperature to transition from parallel to anti-parallel

- The Boltzmann equation tells us the ratio of parallel to antiparallel HI atoms
- The calculation applies to systems in LTE and non-LTE, but T_S means different things
  - In LTE, T_S represents a physical temperature
  - In non-LTE, T_S is an ‘excitation’ temperature

Question Time!

If the ISM at LTE has a temperature of 150 K, what is the ratio of parallel to anti-parallel HI atoms?

Some helpful information:

- $\Delta E = h\nu$
- $h=6.63\times10^{-27}$ ergs/s
- $k=1.38\times10^{-16}$ ergs/K

Hint: There are some assumptions you can make to simplify your calculations!

Total number density of HI atoms

- With the assumption that $\Delta E << kT_S$ we can derive an equation for N_{HI} in terms of only N_L

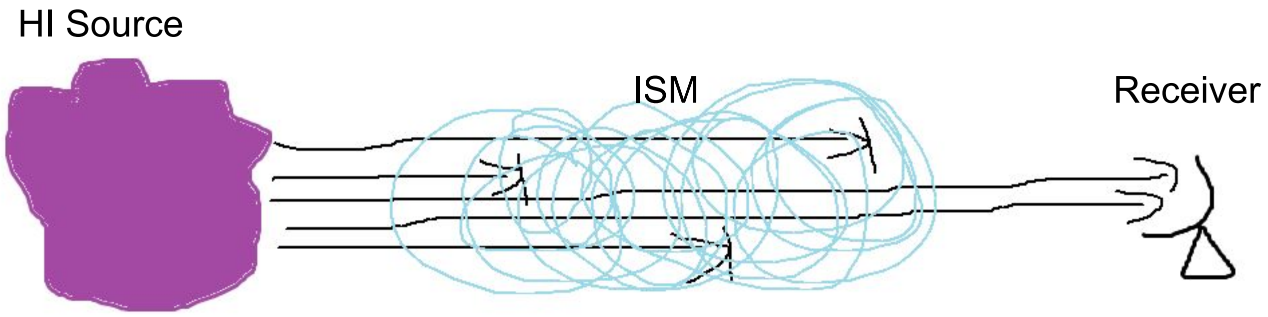
$$\frac{N_u}{N_L} = \frac{g_u}{g_L} = 3$$

$$N_u = 3N_L$$

$$N_{HI} = N_u + N_L = 4N_L$$

This will become important in the next couple slides

Opacity



Some signal from an HI source will get absorbed along the line of sight from Earth to the source

We can represent the probability of absorption along the line of sight with the opacity coefficient

Q: What are some things we need to take into account to quantify the opacity coefficient?

Opacity Coefficient

$$\kappa_\nu = \frac{hc^2 N_L A_{UL}}{8\pi\nu_0 k T_S} \frac{g_U}{g_L} \phi(\nu)$$

Recall $A_{UL} \rightarrow A_{HI} \quad \frac{g_U}{g_L} = 3 \quad N_L = \frac{1}{4} N_{HI} \quad \nu_0 \rightarrow \nu_{HI}$

$$\kappa_\nu = \frac{3c^2}{32\pi} \frac{A_{HI} N_{HI}}{\nu_{HI}} \frac{h}{kT_S} \phi(\nu)$$

Emission line profile

Column Density

$$\eta_{\mathrm{H}} = \int_{\mathrm{los}} \mathrm{N}_{\mathrm{HI}}(\mathrm{s})\mathrm{ds}$$

Recall total opacity $$\mathrm{d}\tau = -\kappa_\nu \mathrm{ds} \Rightarrow \tau = (\mathrm{consts.})\frac{\phi(\nu)}{\mathrm{T_s}}\eta_{\mathrm{HI}}$$

We can rewrite opacity in terms of column density

Q: What is the relationship between spin temperature and brightness temperature in an optically thin medium at LTE?

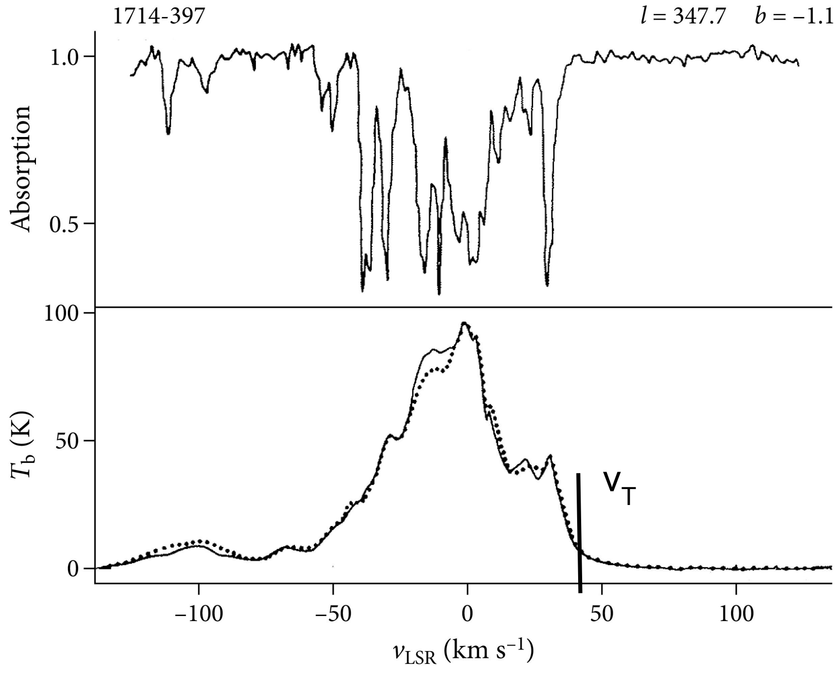
$$\mathrm{T_B} \simeq \mathrm{T_s}\tau \quad \Rightarrow \quad \mathrm{T_B} \propto \mathrm{T_s}\frac{\phi(\nu)}{\mathrm{T_s}}\eta_{\mathrm{H}}$$

Column density is only dependent on brightness temperature!

$$\eta_{\mathrm{H}} = 1.8224 \times 10^{-18}(\mathrm{cm}^{-2}) \int_{-\infty}^{\infty} (\frac{\mathrm{T_B}}{\mathrm{K}})(\frac{\mathrm{dv}}{\mathrm{km/s}})$$

Column Density

At last we look at observables!



$$v_T = R_\odot(\omega R_{min} - \omega_\odot)\sin(l)$$

Write this equation down!

Now to the whiteboard!