The Interstellar Medium

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What is the ISM?

- Everything that is not stars and blackholes

- Molecular clouds are just dense regions of the ISM

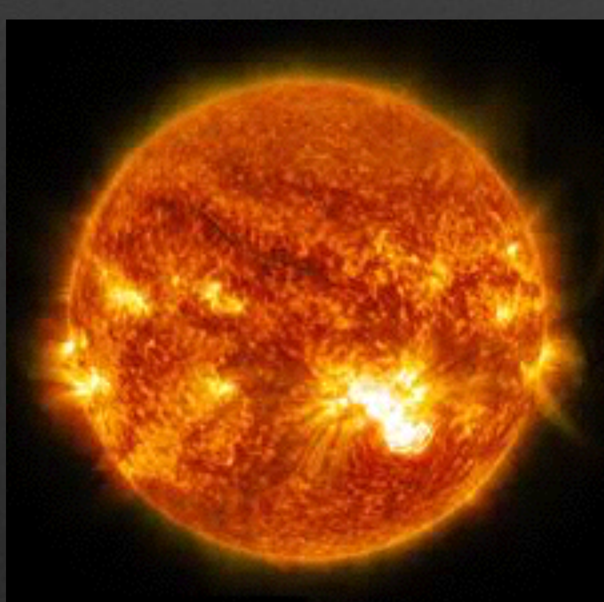
- Globular clusters are tiny star dense regions within the ISM

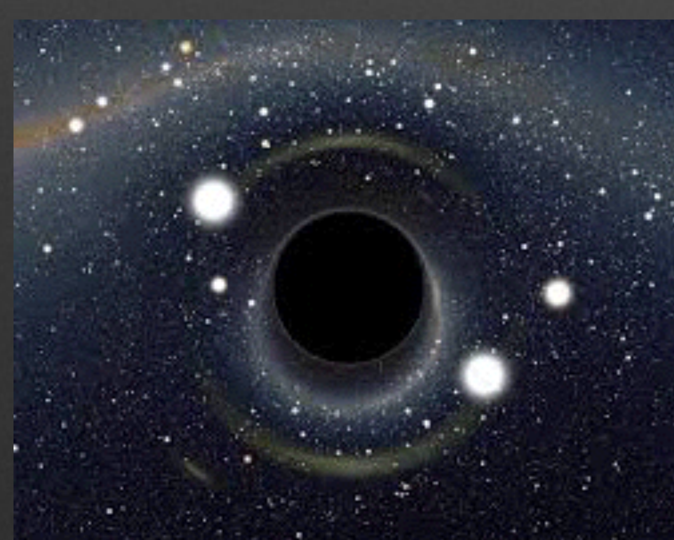
- Cold dense phase ($T<300K$)

- Warm intercloud phase ($T \sim 10^4 K$)

- Hot shock phase ($T \sim 10^6 K$)

Not ISM

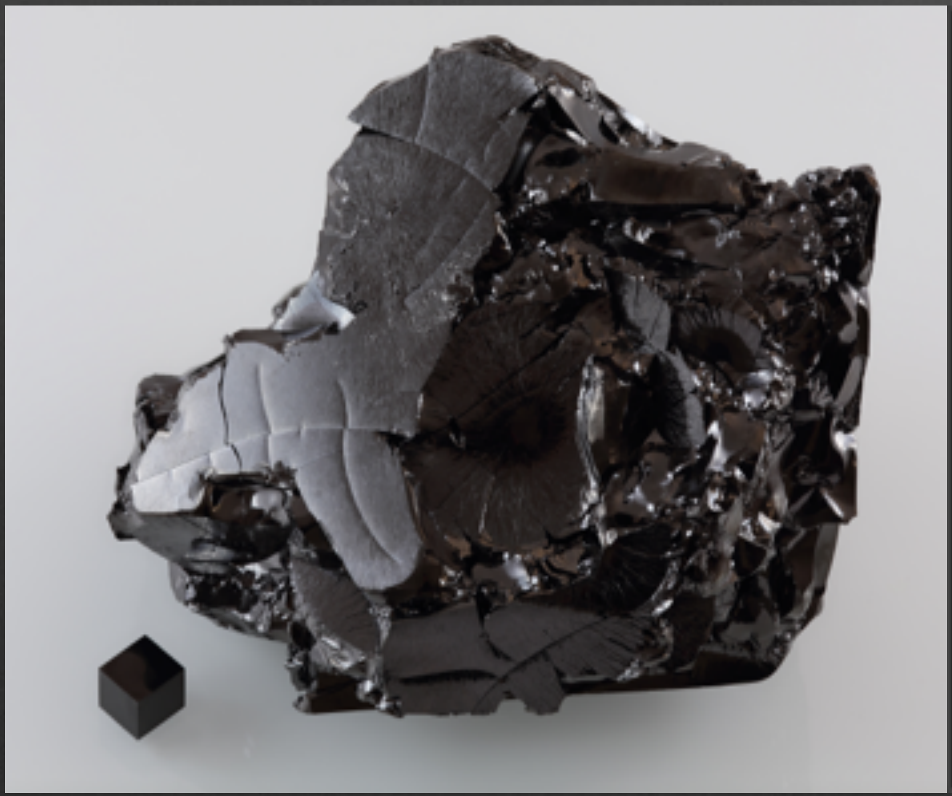




ISM

Composition of ISM

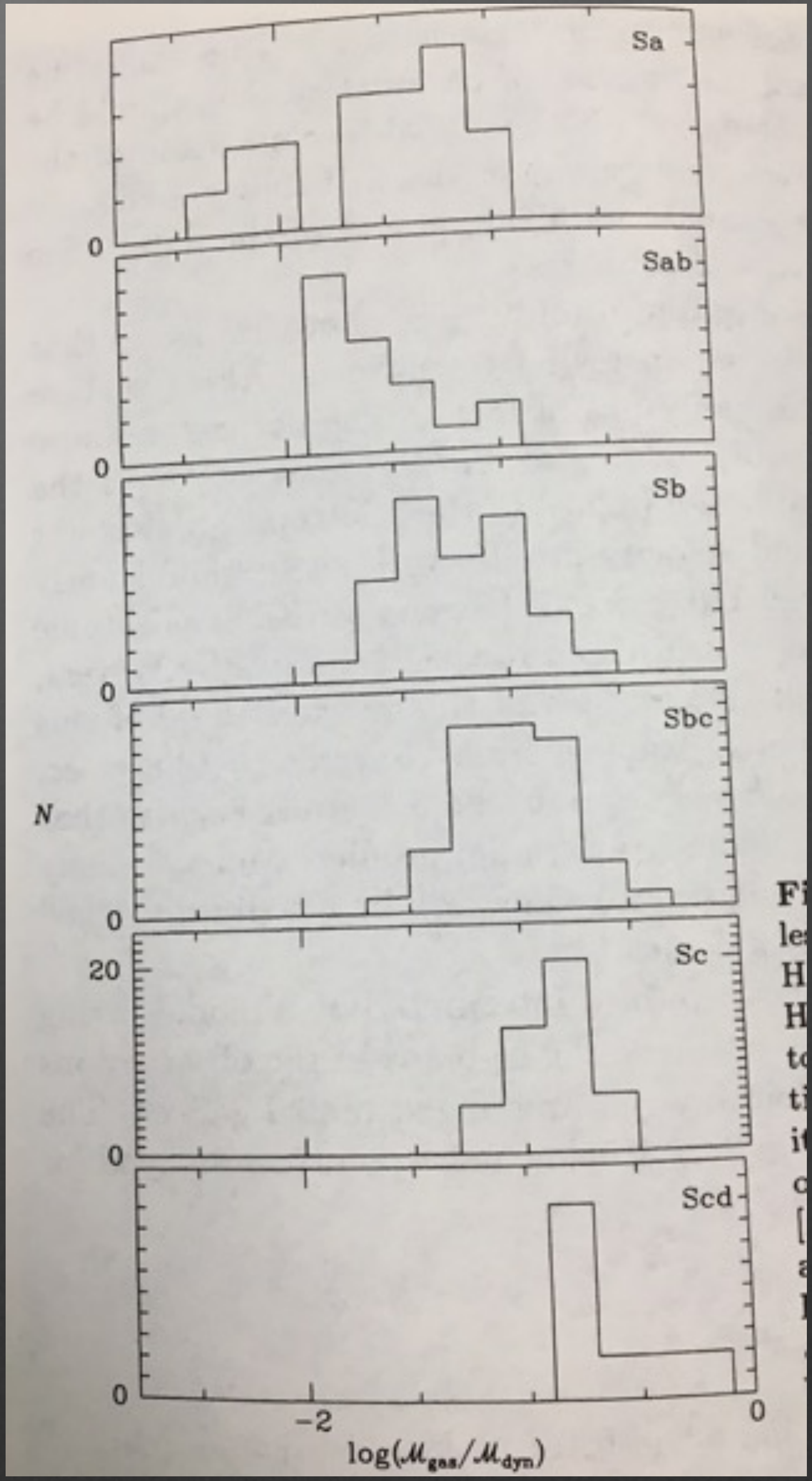
- Sparse Gas
  - HI, H_2, HII, CO
- Dust particles
  - Carbon, Silicon, Oxygen
- Magnetic Fields
- Electrons, Protons
- Atomic Nuclei




Spiral Galaxies

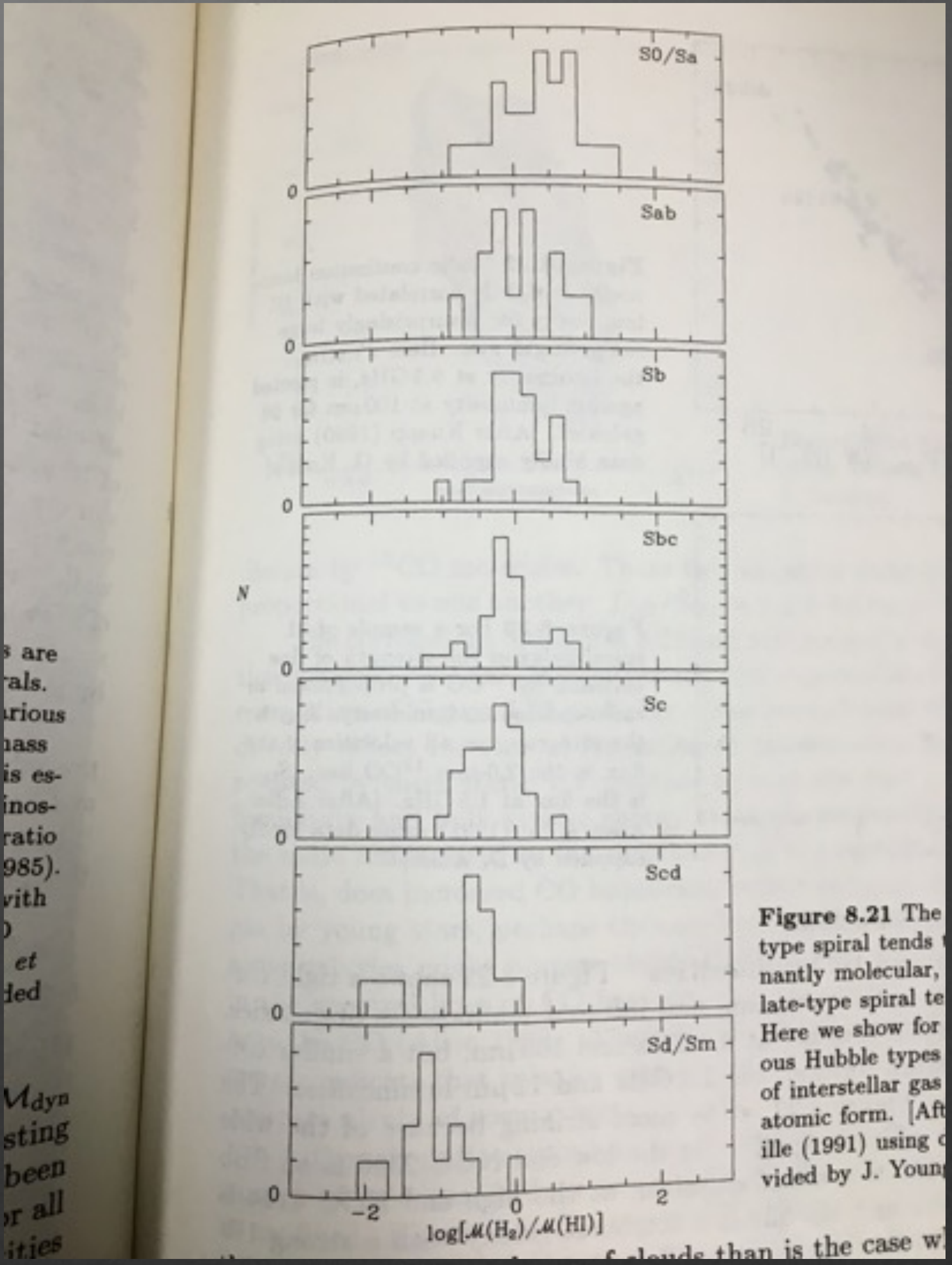
Galactic Composition

- Mostly HI and H_2
- Easiest to determine mass of HI and ^{12}CO
- H_2 to ^{12}CO ratio is 10^4:1
- Total mass in a galaxy ranges wildly
- More interesting is mass ratio of ISM gas mass to galactic mass
- This ratio depends on Hubble type



Galactic Composition

- Another interesting ratio is the ratio between HI and H_2
- However the H_2 component being derived from the ^{12}CO amount
- It is assuming the H_2: ^{12}CO ratio is the same for all galaxy types



CO->H_2

- H_2 being a symmetric molecule makes it difficult to observe
- We use a temperature density of CO: I_{CO} which has units of (K Km s^{-1})
- And measure in the milkyway $X=N(H_2)/I_{CO}=2.3E24$
- X increases with metallicity
- This is a poor way to determine H_2 amount

Milky Way Composition

Component	*Description*	*Density* (cm^{-3})	*Temperature* (K)	*Pressure* (p/k_B)	*Vertical extent*	*Mass* ($\mathcal{M}_\odot$)	*Filling factor*
Dust grains						10^7–10^8	Tiny
large $\lesssim 1\ \mu m$	Silicates, soot		~ 20		150 pc		
small ~ 100 Å	Graphitic C		30–100				
PAH < 100 atoms	Big molecules				80 pc		
Cold clumpy gas	Molecular: H_2	> 200	< 100	Big	80 pc	$(2) \times 10^9$	<0.1%
	Atomic: HI	25	50–100	2 500	100 pc	3×10^9	2%–3%
Warm diffuse gas	Atomic: HI	0.3	8 000	2 500	250 pc	2×10^9	35%
	Ionized: HII	0.15	8 000	2 500	1 kpc	10^9	20%
HII regions	Ionized: HII	1–10^4	$\sim 10\,000$	Big	80 pc	5×10^7	Tiny
Hot diffuse gas	Ionized: HII	~ 0.002	$\sim 10^6$	2 500	~ 5 kpc	(10^8)	45%
Gas motions	$\frac{3}{2}\langle\rho_{HI}\rangle\sigma_r^2$	$\langle n_H \rangle \sim 0.5$	$10\ km\ s^{-1}$	8 000			
Cosmic rays	Relativistic	$1\ eV\ cm^{-3}$		8 000	~ 3 kpc	Tiny	
Magnetic field	$B \sim 5\ \mu G$	$1\ eV\ cm^{-3}$		8 000	~ 3 kpc		
Starlight	$\langle \nu h_P \rangle \sim 1$ eV	$1\ eV\ cm^{-3}$			~ 500 pc		
UV starlight	11–13.6 eV	$0.01\ eV\ cm^{-3}$					

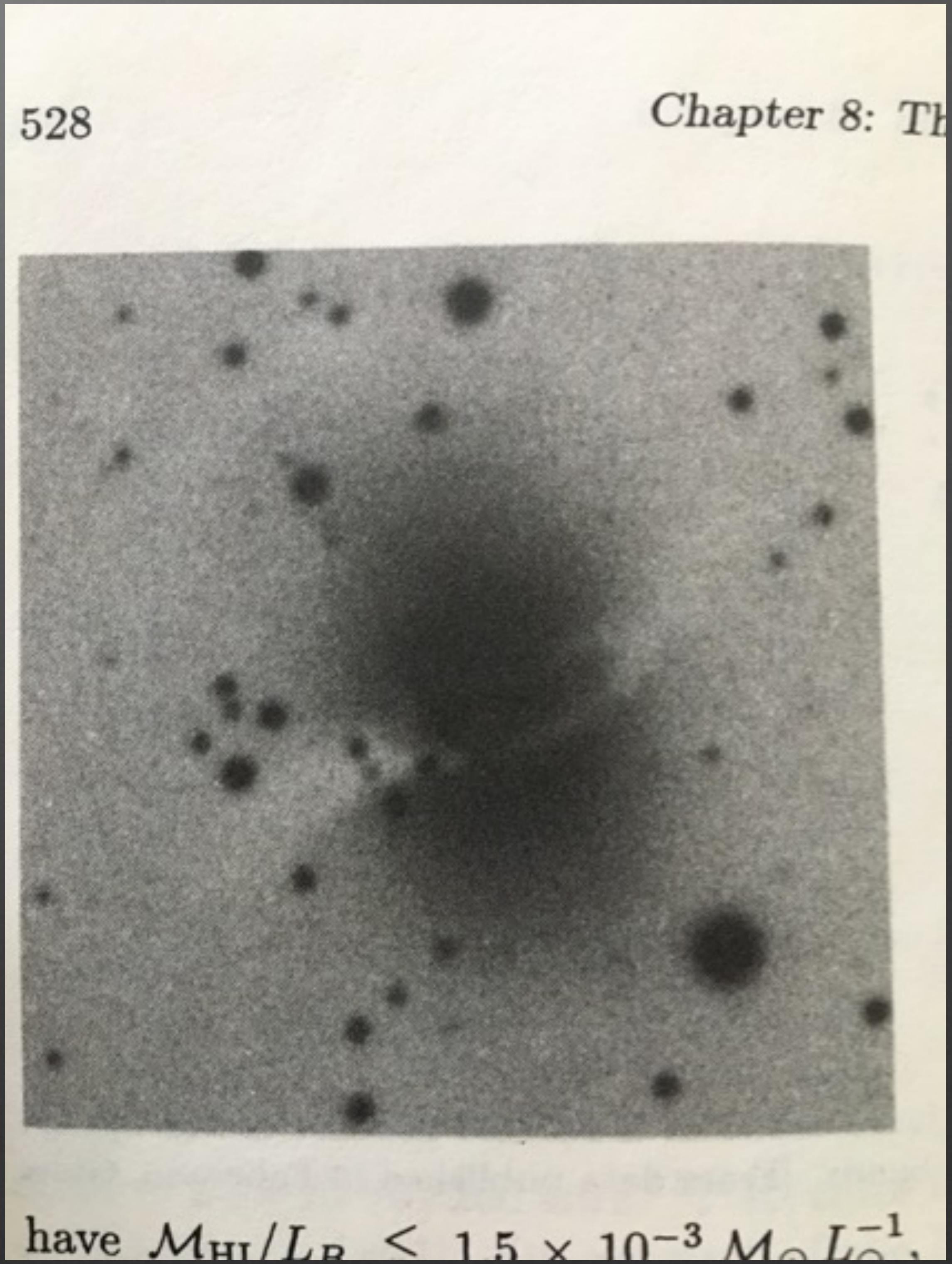
Elliptical Galaxies

Galactic Composition

- Mostly hot plasma (T>10^6K)
- It is difficult to determine amounts of cool gas
- ^{12}CO has only been detected in ~40% of ellipticals
- Dust particles often form a dust lane which rotates perpendicular to most of the stars

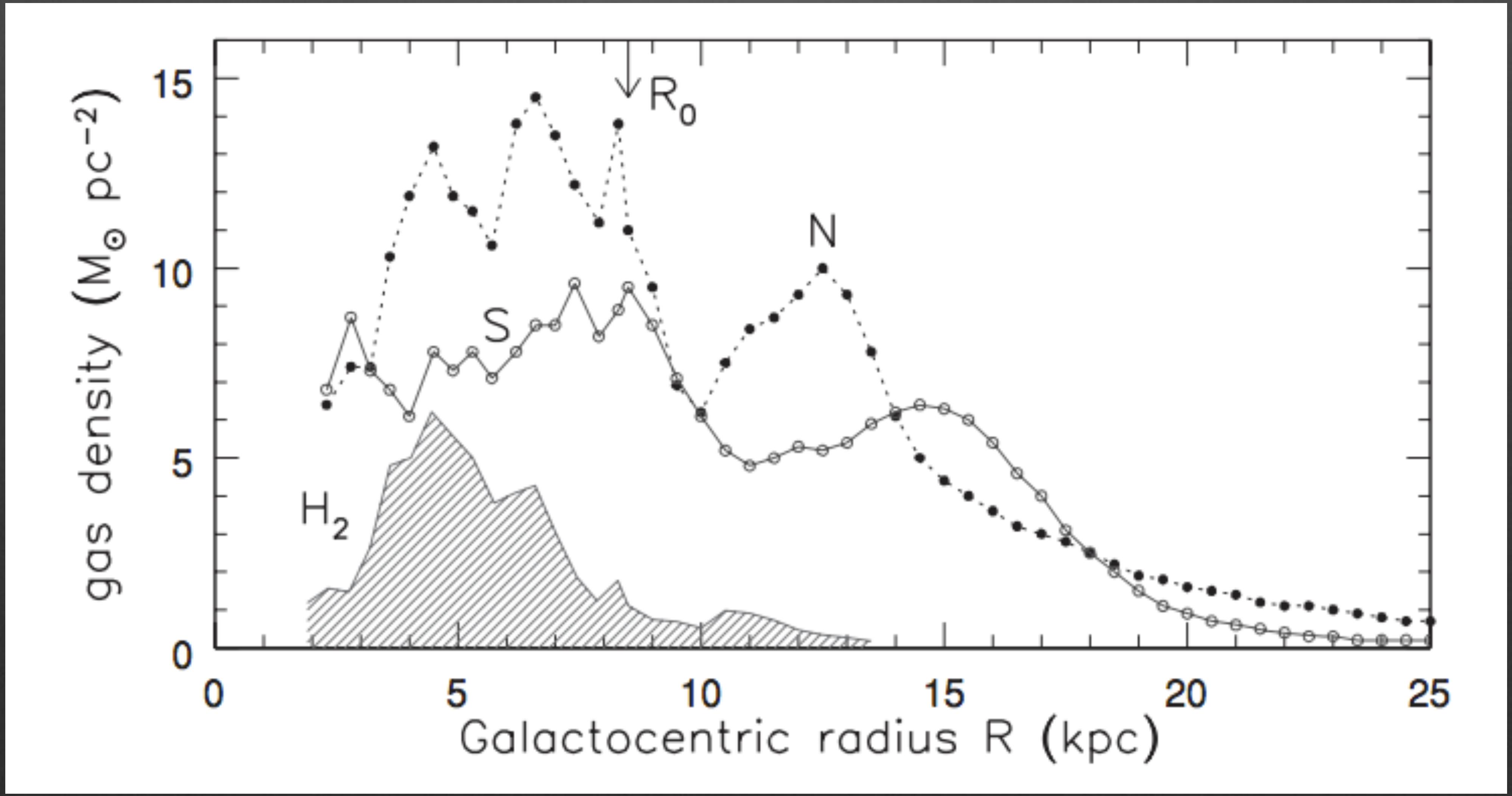
Dust Lanes

- Dust is usually thought to be ejecta from supernova
- Dust lanes can't really be reconciled with this theory because they don't usually rotate parallel to most of the stars
- We don't see them in spirals
- We expect that this gas has fallen in from outside of the galaxy



Observations

- HI from the 21 cm line
- ^{12}CO from the 2.6mm and 1.3mm line
- Total gas amount can be determined from the amount of cosmic rays detected vs the amount of gamma rays that we see from the same area



HII & HI Emission

Balmer Lines

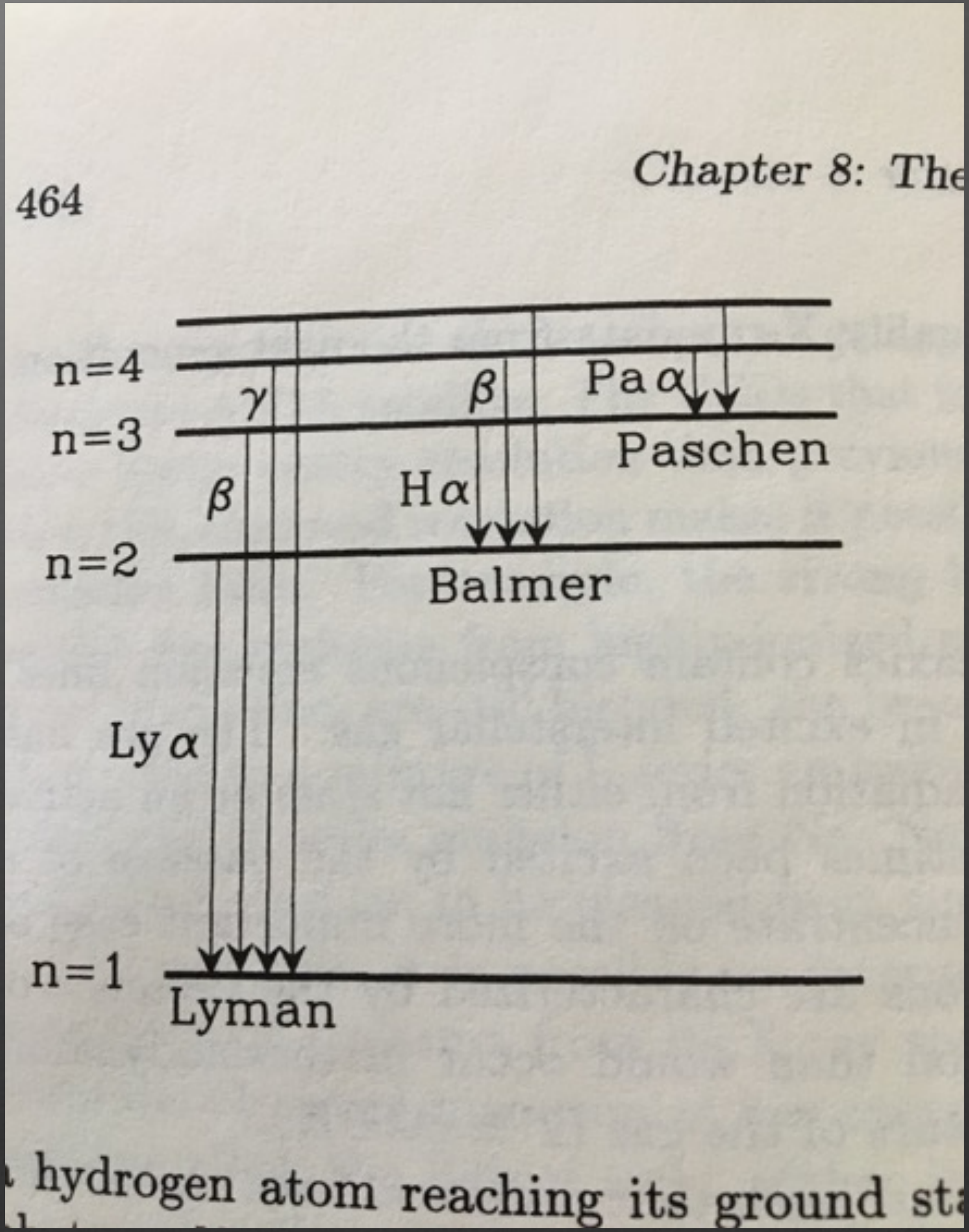
- HII regions emit lines in the Balmer series

- The Lyman series photons are too easily reabsorbed by the gas

- H_{alpha} =656nm, H_{beta} =486nm, H_{gamma} =434nm

- There is a discrepancy between observed and predicted H_{alpha}/H_{beta} ratios

- This is due to absorption by dust



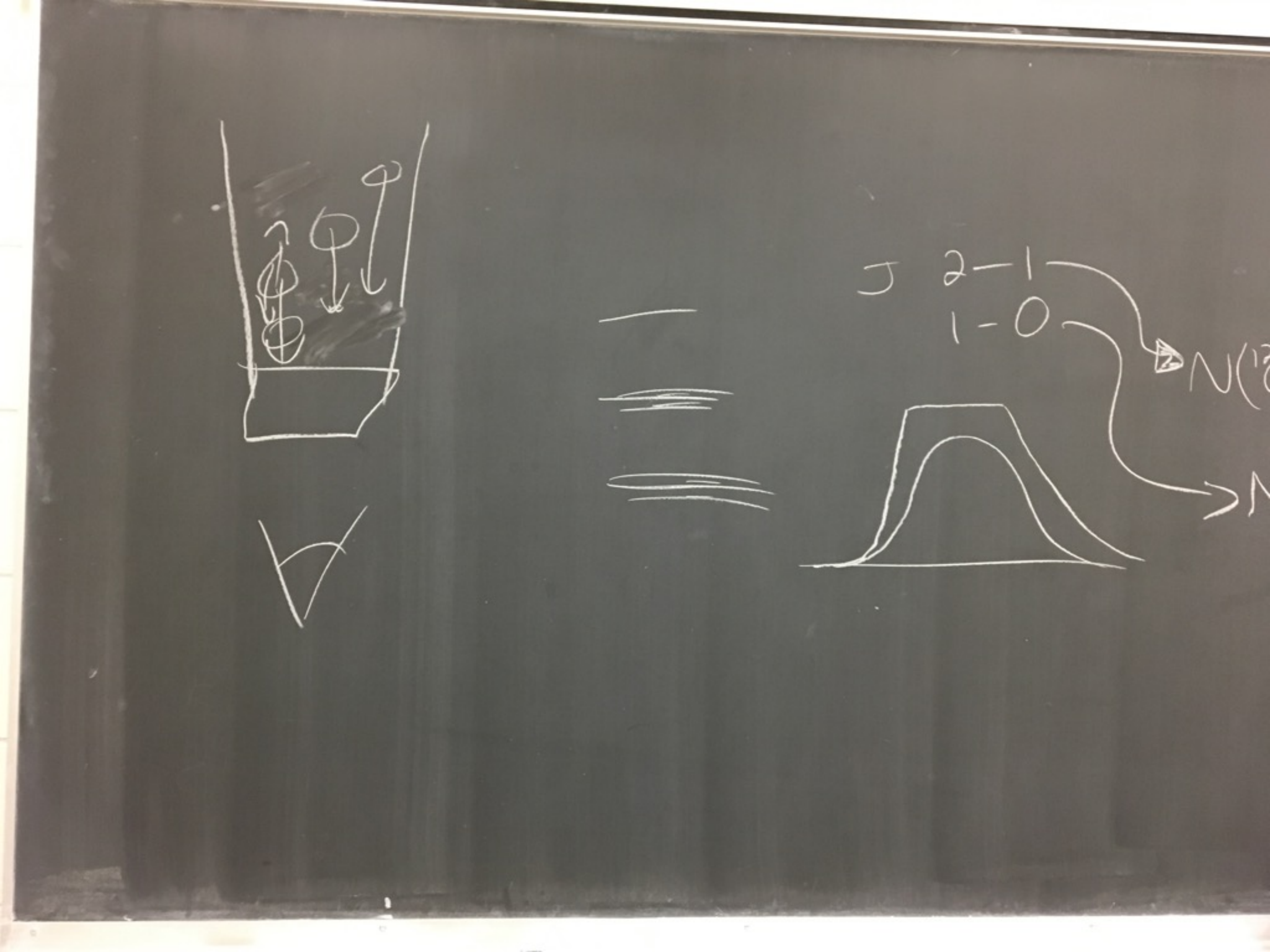
21cm Line

- The ground level on atomic hydrogen is split into two states
- Parallel vs Antiparallel spins of the electron and proton
- This spin flip transition happens spontaneously only about once in 10^7 years
- However it can happen about 400 times a year due to collisions
- Since it is collision dominated it is entirely temperature and density dependant

Gamma Radiation

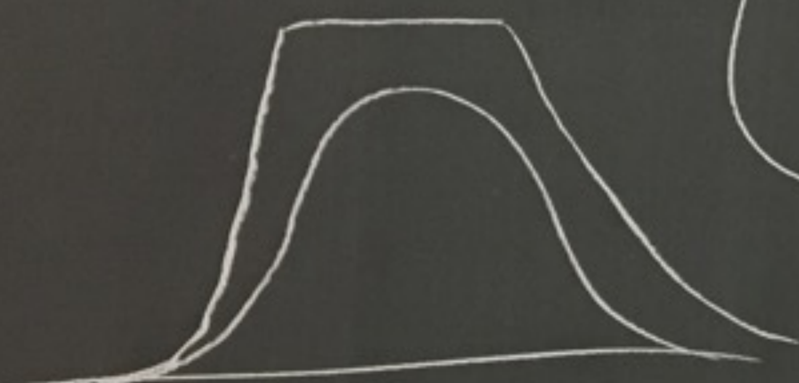
- Densest regions glow with gamma radiation
- Caused when photons collide with high energy nuclei and electrons
- Called Inverse-Compton scattering
- Also caused by emissions from collisions between two high energy charged particles

Blackboard Equations/ Diagrams


J 2–1
1–0

J 2—1

1—0



atoms/m^2(km/s)

$N(^{12}CO) = 5.5 \times 10^{19}$ $\quad N(H_2) = 3.9 \times 10^{23}$

$N(^{12}CO) = 2.2 \times 10^{20}$ $\quad N(H_2) = 1.7 \times 10^{24}$

(v)

column density →

$/m^2 H_2$

We measure in:

Janskys/beam · channel

channel [km/s]

column → $N_H = 1.82 \times 10^{22} \int_{-\infty}^{\infty} dv\, T\, \tau(v)$ [atoms/m²]
density

(T ← spin temp)

$N_H = 1.82 \times 10^{20} \int_{-\infty}^{\infty} dv \int_{\Omega} d\Omega\, T_B(l, b, v)$ [atoms]

(T_B ← brightness temp)

sure in:

/beam · channel

nnel [Km/s]

$$\frac{M_H}{M_\odot} = 2.36 \times 10^5 \left(\frac{D}{\text{Mpc}}\right)^2 \int_{-\infty}^{\infty} d\nu \, S(\nu)$$

$10^{-26}\ \text{W}/\text{m}^2\,\text{Hz}$

$$\frac{dI_\nu}{ds} = \left(\frac{h\nu}{4\pi}\right)\left[n_2^{(\nu)} A_{21} - \left(n_1^{(\nu)} B_{12} - n_2^{(\nu)} B_{21}\right)\frac{4\pi I_\nu}{c}\right)$$

n_i ← # density of atoms

i is # photons can be absorbed/emitted at frequency ν

$$\frac{dI_\nu}{d\tau_\nu} + I_\nu = S_\nu$$

S_ν ← source function at ν

$d\tau_\nu$ ← $\equiv$ optical depth

ed

Einstein Coefficients

(probability of absorption/emission)

$$\chi_\nu = \frac{h\nu}{c}\left(n_1^{(\nu)} B_{12} - n_2^{(\nu)} B_{21}\right)$$

$$\tau_\nu = \int \chi_\nu \, ds$$

References

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- Jayanne's Website: http://www.physics.umanitoba.ca/~english/astroimages.html#newhcg31
- Images: https://en.wikipedia.org/wiki/Carbon#/media/File:Glassy_carbon_and_a_1cm3_graphite_cube_HP68-79.jpg, https://commons.wikimedia.org/wiki/File:SiliconCroda.jpg, http://www.periodictable.com/Items/008.10/index.html