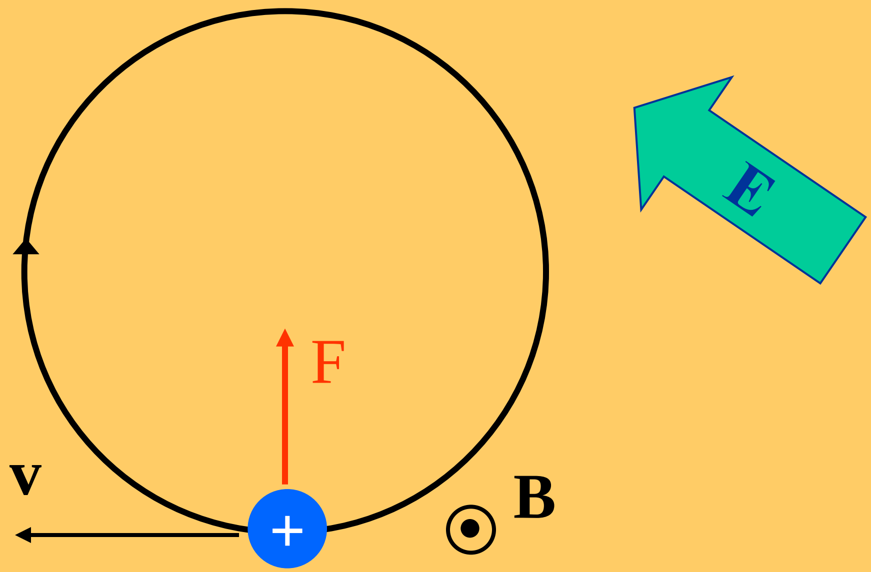
Think about this:

$$\mathbf{F} = q\mathbf{v} \times \mathbf{B}$$



What happens if you add an electric field **E**?

Last lecture (3)

- Solar activity
- Solar wind – basic facts
- Solar wind – magnetic structure

Today's lecture (4)

- Ionosphere

  - layers

  - radio wave reflection

Today

Activity	Date	Time	Room	Subject	Litterature
L1	31/8	13-15	V22	Course description, Introduction, The Sun 1, Plasma physics 1	CGF Ch 1, 5, (p 110-113)
L2	3/9	15-17	Q36	The Sun 2, Plasma physics 2	CGF Ch 5 (p 114-121), 6.3
L3	7/9	13-15	Q36	Solar wind, The ionosphere and atmosphere 1, Plasma physics 3	CGF Ch 6.1, 2.1-2.6, 3.1-3.2, 3.5, LL Ch III, Extra material
T1	10/9	15-17	Q36	Mini-group work 1	
L4	14/9	13-15	E2	The ionosphere 2, Plasma physics 4	CGF Ch 3.4, 3.7, 3.8
T2	17/9	8-10	Q31	Mini-group work 2	
L5	17/9	15-17	L52	The Earth's magnetosphere 1, Plasma physics 5	CGF 4.1-4.3, LL Ch I, II, IV.A
L6	21/9	13-15	L52	The Earth's magnetosphere 2, Other magnetospheres	CGF Ch 4.6-4.9, LL Ch V.
T3	24/9	16-18	Q36	Mini-group work 3	
L7	28/9	13-15	Q36	Aurora, Measurement methods in space plasmas and data analysis 1	CGF Ch 4.5, 10, LL Ch VI, Extra material
T4	1/10	15-17	V22	Mini-group work 4	
L8	5/10	13-15	M33	Space weather and geomagnetic storms	CGF Ch 4.4, LL Ch IV.B-C, VII.A-C
L9	6/10	8-10	Q36	Interstellar and intergalactic plasma, Cosmic radiation,	CGF Ch 7-9
T5	8/10	15-17	Q34	Mini-group work 5	
L10	12/10	13-15	Q36	Swedish and international space physics research.	
T6	15/10	15-17	Q33	Round-up.	
Written examination	28/10	8-13	Q21, Q26		

L = Lecture, T = Tutorial

Mini groupwork 1

a)

$$h = \frac{17}{2} \cdot 6378 \text{ km}$$

The thermal energy is divided into motion in the three dimensions, two of which only give rise to a gyro motion around the magnetic field lines, with the motion along the magnetic field corresponding to an energy

$$E = \frac{k_B T}{2} = \frac{1.38 \cdot 10^{-23} \cdot 2 \cdot 10^{6}}{2} = 1.4 \cdot 10^{-17} \text{ J}$$

$$v = \sqrt{\frac{2E}{m_e}} = \sqrt{\frac{2 \cdot 1.4 \cdot 10^{-17}}{0.91 \cdot 10^{-30}}} = 5500 \text{ km/s}$$

Approximating the loop with a quarter-circle, the electron has to travel a length

$s = \pi h/2 = 85\ 000$ km

Then we get $t = 15$ s.

Energy - temperature

Average energy of molecule/atom:

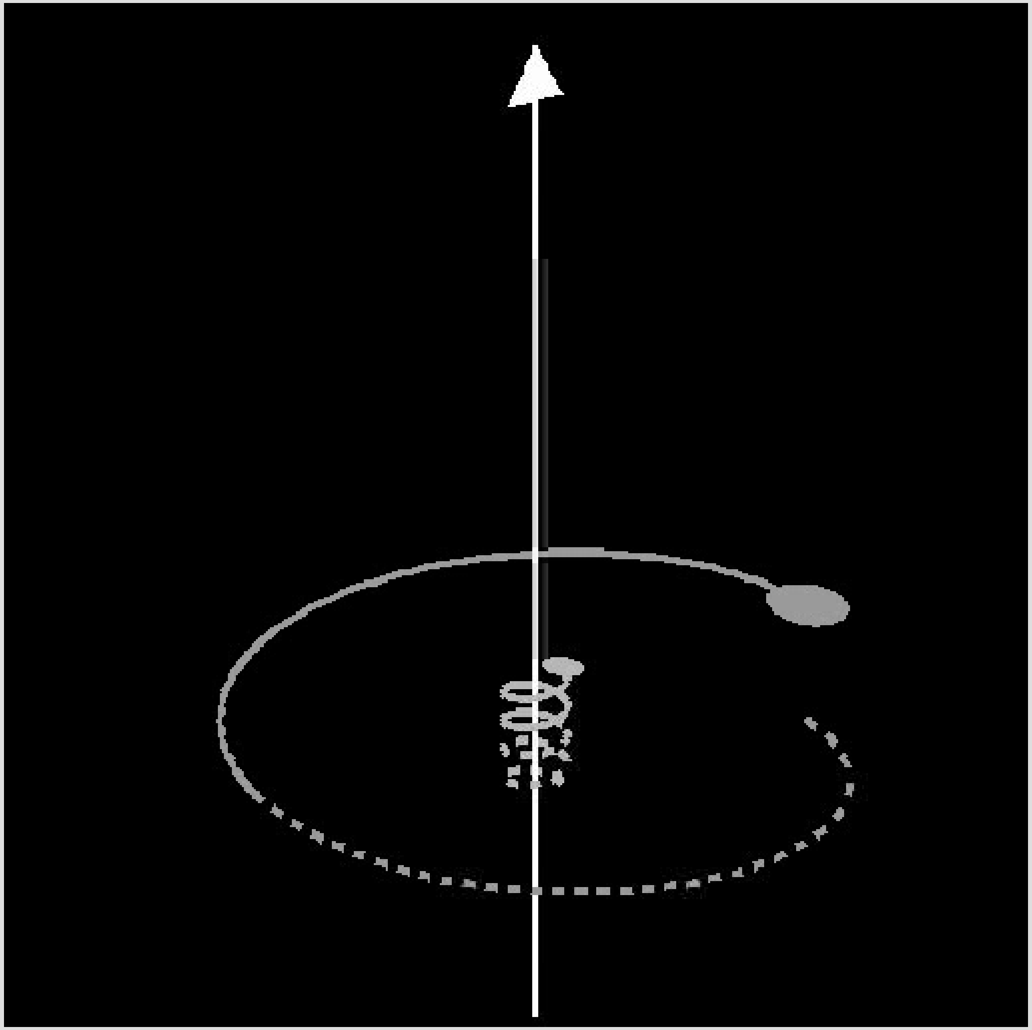
$$E = \frac{3}{2} k_B T \quad \Rightarrow$$

$$T = \frac{2E}{3k_B}$$

1 eV = $1.6 \cdot 10^{-19}$ J $\Rightarrow$

$$T = \frac{2E}{3k_B} = \frac{2 \cdot 1.6 \cdot 10^{-19}\,\mathrm{J}}{3 \cdot 1.38 \cdot 10^{-23}\,\frac{\mathrm{J}}{\mathrm{K}}} = 7729\,\mathrm{K}$$

Gyro motion



Equipartion principle

Statistically the kinetic energy is equally distributed along the three dimensions:

$$E_{\parallel} = \frac{1}{2} k_B T$$

$$E_{\perp} = \frac{2}{2} k_B T$$

Mini groupwork 1

b)

$$f_c = \frac{\omega_c}{2\pi} = \frac{1}{2\pi}\frac{qB}{m} \quad \Rightarrow$$

$$B = \frac{2\pi f_c m}{q} = \frac{2\pi \cdot 8\cdot 10^{9} \cdot 0.91\cdot 10^{-30}}{1.6\cdot 10^{-19}} = 0.29 \text{ T}$$

The perpendicular energy is given by

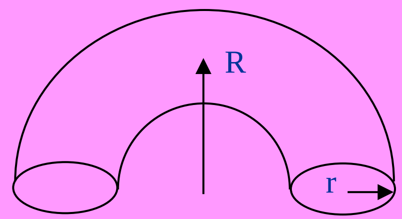
$$E = \frac{2k_B T}{2} = \frac{2\cdot 1.38\cdot 10^{-23} \cdot 2\cdot 10^{6}}{2} = 2.8\cdot 10^{-17} \text{ J}$$

$$v_\perp = \sqrt{\frac{2E}{m_e}} = \sqrt{\frac{2\cdot 2.8\cdot 10^{-17}}{0.91\cdot 10^{-30}}} = 7.8\cdot 10^{6} \text{ m/s}$$

$$\rho = \frac{m_e v_\perp}{qB} = \frac{0.91\cdot 10^{-30} \cdot 7.8\cdot 10^{6}}{1.6\cdot 10^{-19} \cdot 0.29} = 1.5\cdot 10^{-4} \text{ m}$$

Mini groupwork 1

c) Model the flare by a half torus with minor axis r, and major axis. From the figure, estimate $R = 8\,R_E$, and $r = 2\,R_E$.



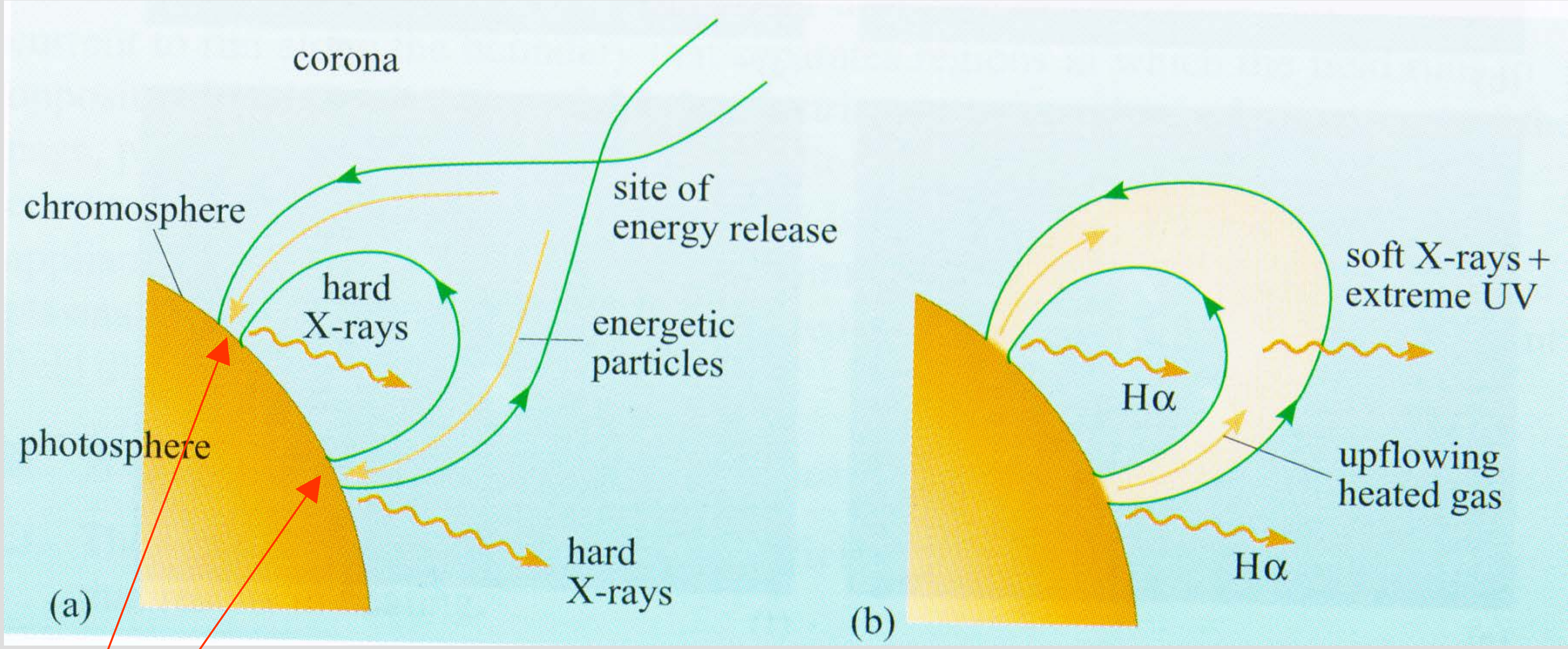
Let this half-torus be filled with a magnetic field of strength B ~ 0.36 T (using the value in b)). If the volume of the half-torus is V and the magnetic energy density is p_B, the total energy is

$$W = Vp_B = \pi R \pi r^2 \frac{B^2}{2\mu_0} = \pi^2 \cdot 8 \cdot 2^2 {R_E}^3 \frac{B^2}{2\mu_0}$$

$$= \pi^2 \cdot 32 \cdot (6378 \cdot 10^3)^3 \frac{(0.29)^2}{2\mu_0}$$

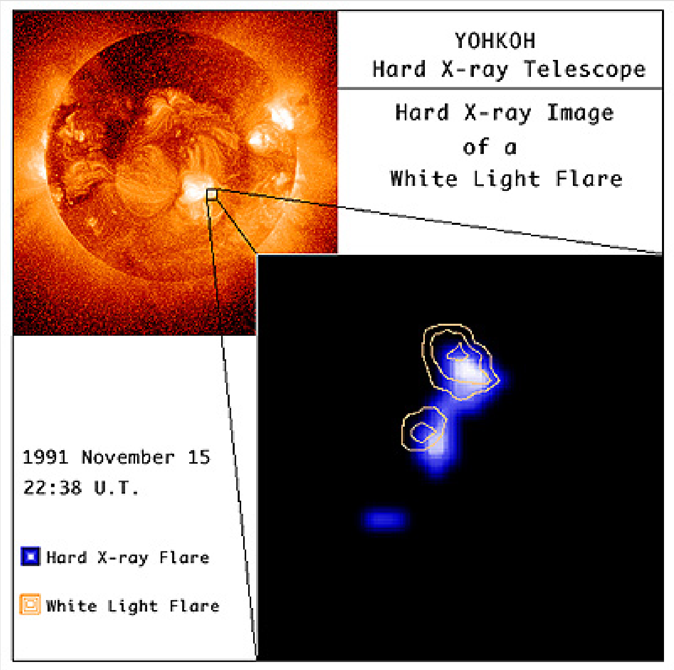
$$= 5.5 \cdot 10^{27}\ \mathrm{J}$$

Solar flare mechanism

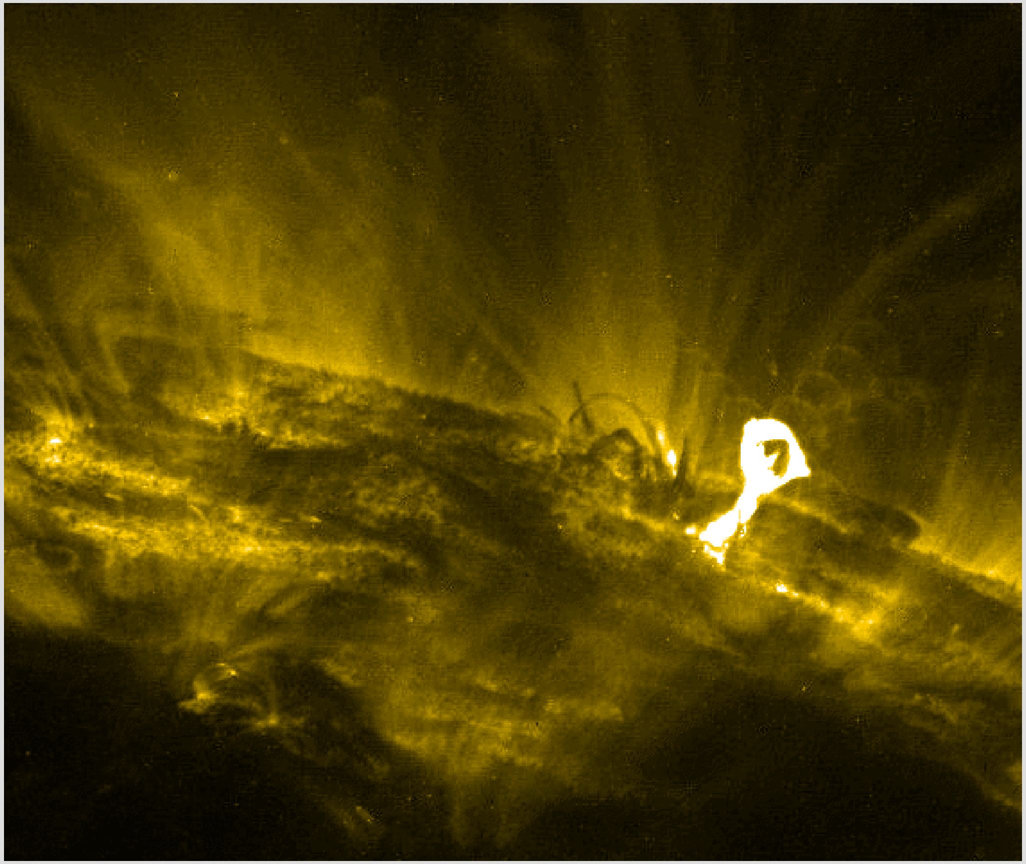


Electrons are accelerated, collide with solar surface (photosphere) and emit bremsstrahlung (X-rays).

Solar flare observations



(a) double signature of x-ray emissions at foot of flare



(b) coronal loop filled with hot gas

Frozen in magnetic flux *PROOF II*

$$\frac{\partial \mathbf{B}}{\partial t} = \underbrace{\nabla \times (\mathbf{v} \times \mathbf{B})}_{A} + \underbrace{\frac{1}{\mu_0 \sigma} \nabla^2 \mathbf{B}}_{B}$$

Order of magnitude estimate:

$$\frac{A}{B} = \frac{\nabla \times (\mathbf{v} \times \mathbf{B})}{\frac{1}{\mu_0 \sigma} \nabla^2 \mathbf{B}} \approx \frac{\frac{v \Delta B}{L}}{\frac{\Delta B}{\mu_0 \sigma L^2}} = v L \mu_0 \sigma \equiv R_m$$

Magnetic Reynolds number R_m:

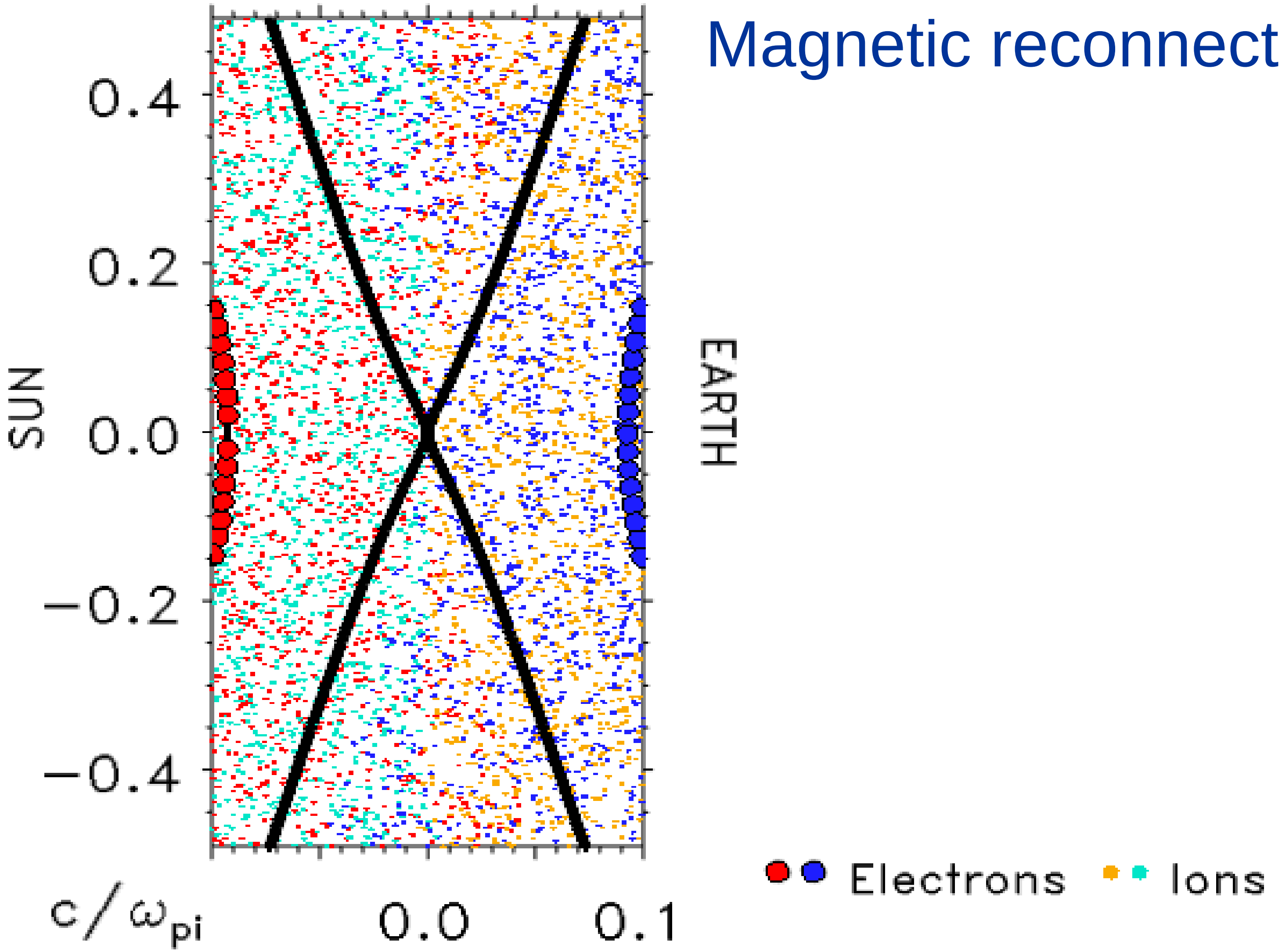
$$\mathrm{R_m} >> 1 \Rightarrow \quad \frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{v} \times \mathbf{B})$$

Frozen-in fields!

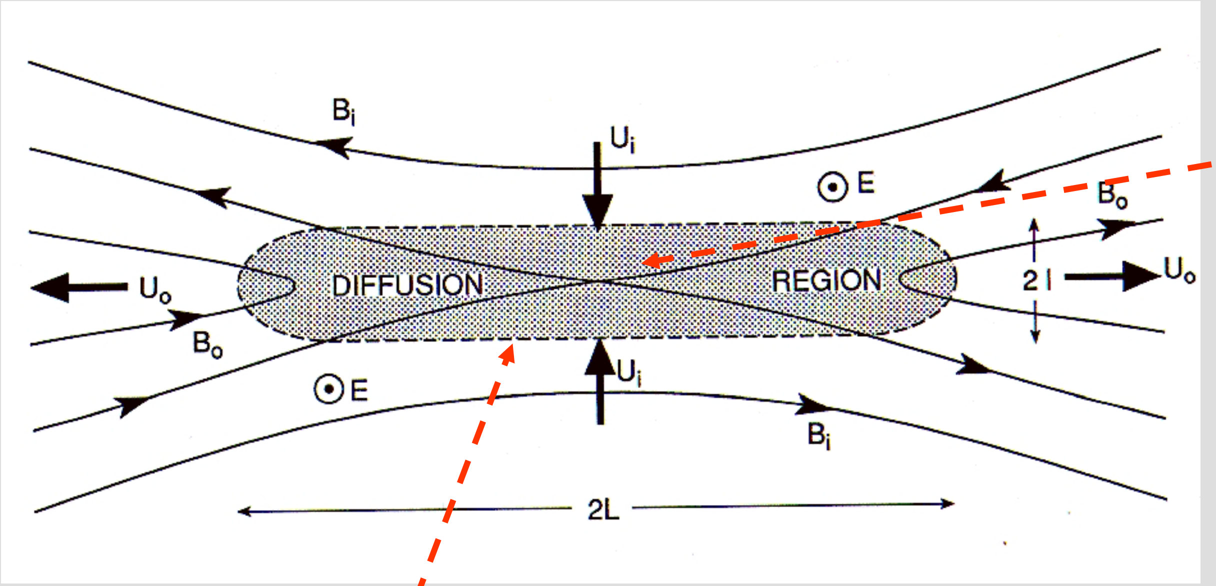
$$\mathrm{R_m} << 1 \Rightarrow \quad \frac{\partial \mathbf{B}}{\partial t} = \frac{1}{\mu_0 \sigma} \nabla^2 \mathbf{B}$$

Diffusion equation!

Magnetic reconnection



Reconnection



In 'diffusion region':

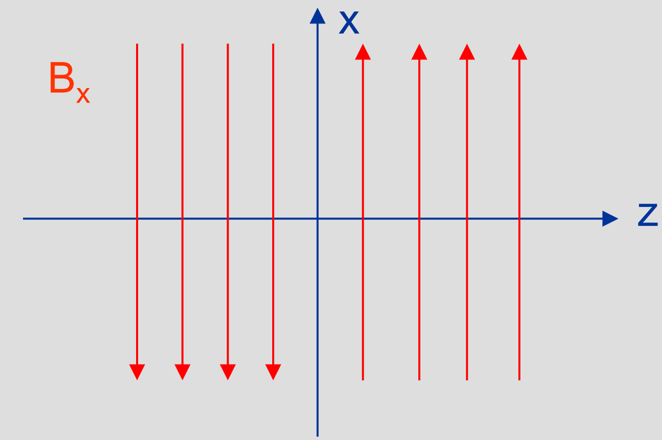
$R_m = \mu_0 \sigma l v \sim 1$

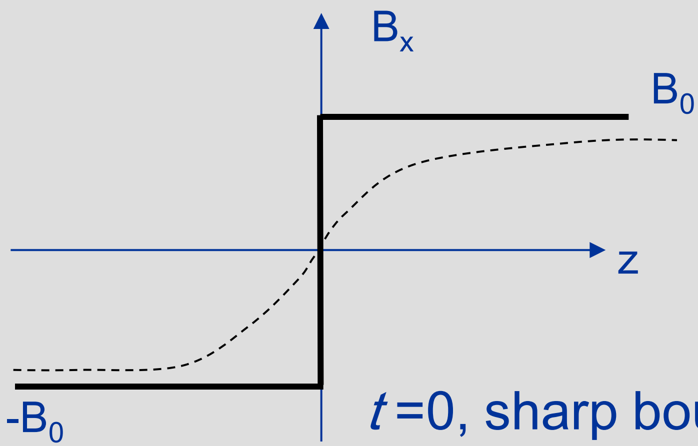
Thus: condition for frozen-in magnetic field breaks down.

A second condition is that there are two regions of magnetic field pointing in *opposite* direction:

- Field lines are "cut" and can be re-connected to other field lines
- **Magnetic energy is transformed into kinetic energy ($U_o >> U_i$)**
- **Plasma from different field lines can mix**

Reconnection in 1D





t =0, sharp boundary

$$\frac{\partial \mathbf{B}}{\partial t} = \frac{1}{\mu_0 \sigma} \nabla^2 \mathbf{B} \longrightarrow \frac{\partial B_x}{\partial t} = \frac{1}{\mu_0 \sigma} \frac{\partial^2 B_x}{\partial z^2}$$

Diffusion equation! Has solution

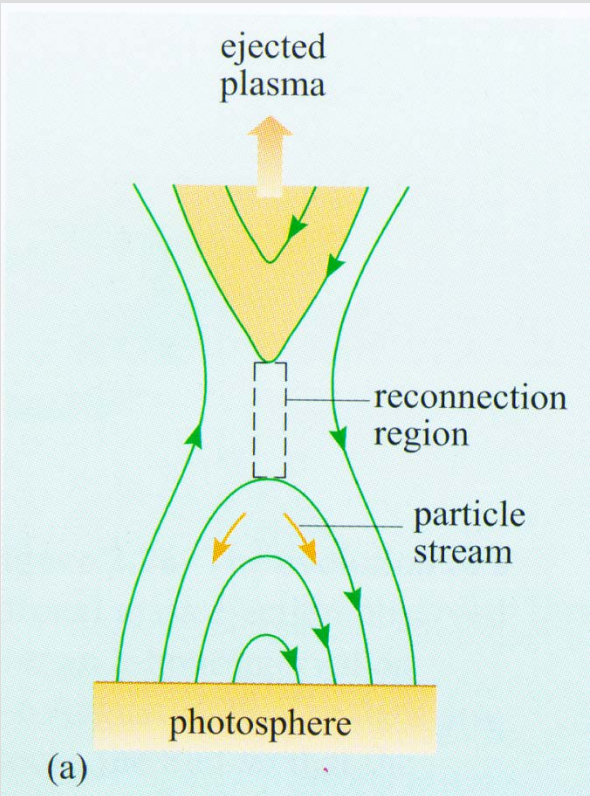
$$B_x(z,t) = B_0 \, erf\left(\left[\frac{\mu_0 \sigma}{4t} \right]^{1/2} z \right)$$

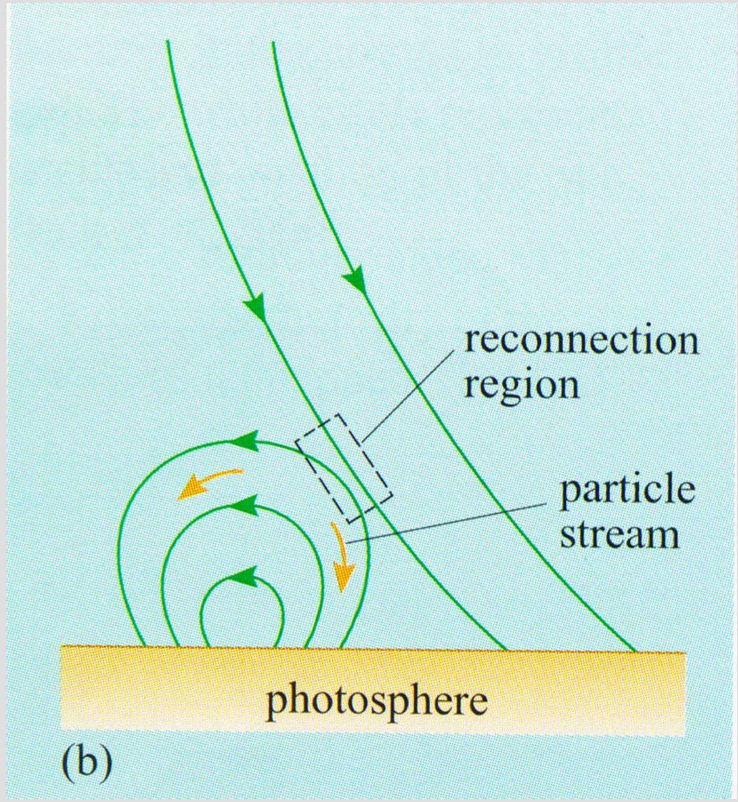
The total magnetic energy then decreases with time:

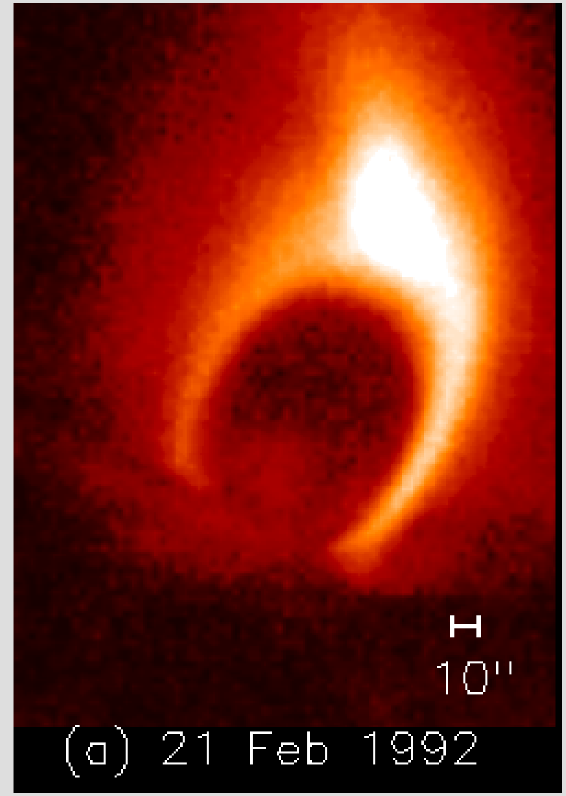
$$W_B = \int_{-\infty}^{\infty} \frac{B^2}{2\mu_0} dz$$

The magnetic energy is converted into heat and kinetic energy in 2D

Solar flare
energization mechanism



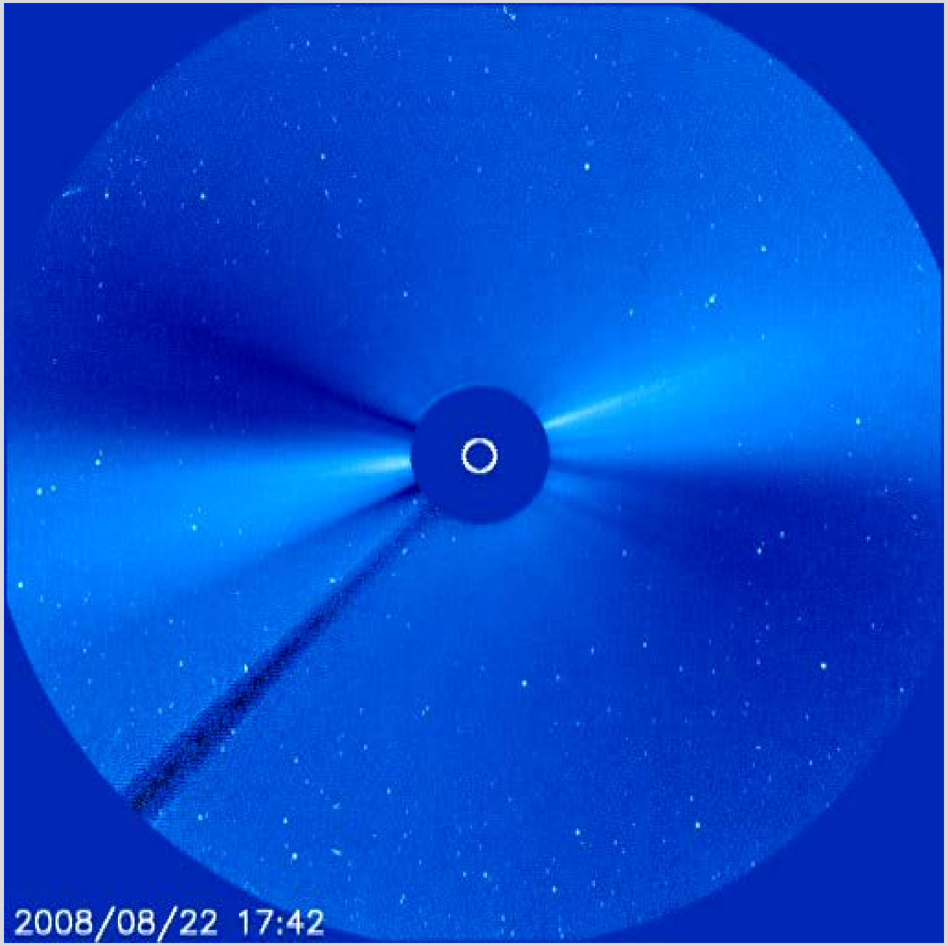




Two possible reconnection geometries

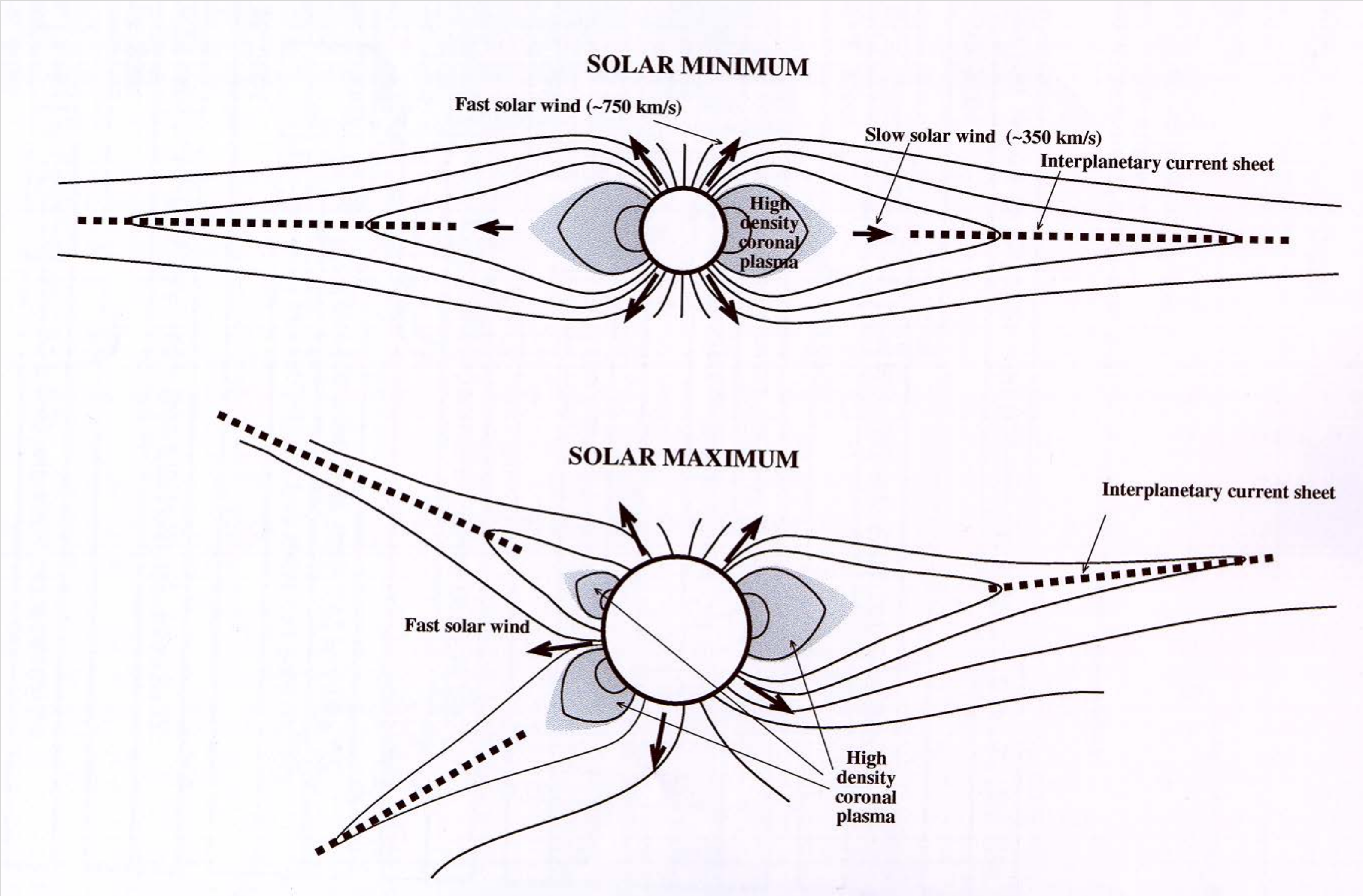
Solar wind

Corona continuously merges into solar wind



Solar and Heliospheric Observatory (SOHO)
LASCO C3 Coronagraph Movie

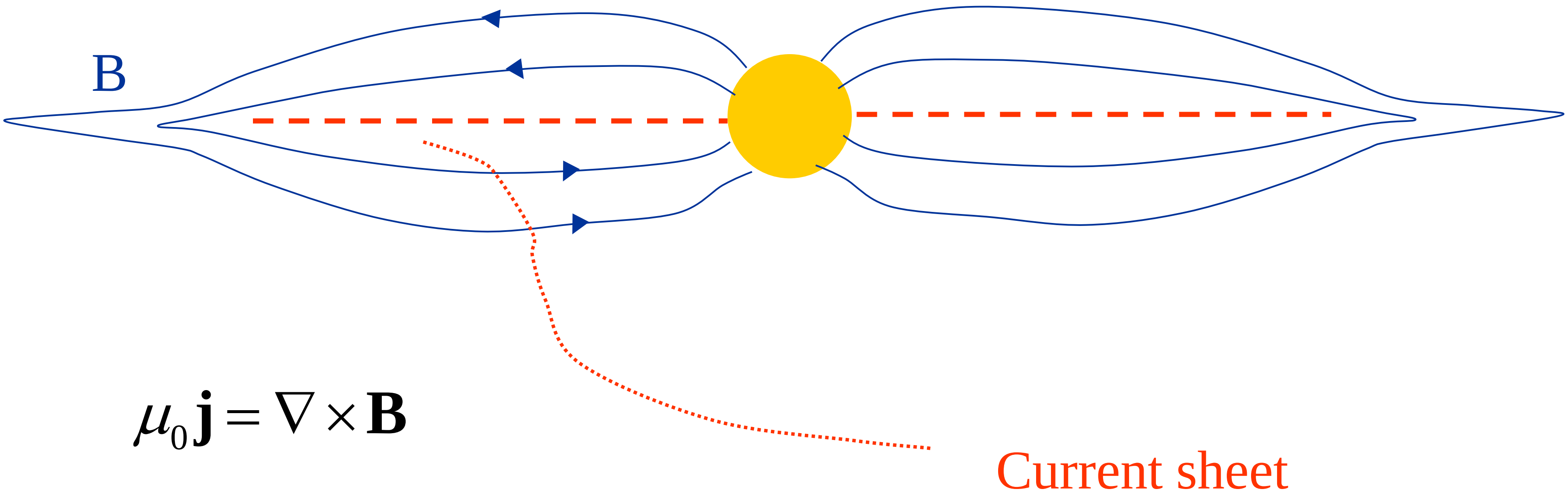
Solar wind



SOLAR MINIMUM
Fast solar wind (~750 km/s)
Slow solar wind (~350 km/s)
Interplanetary current sheet
High density coronal plasma
SOLAR MAXIMUM
Interplanetary current sheet
Fast solar wind
High density coronal plasma

Solar wind

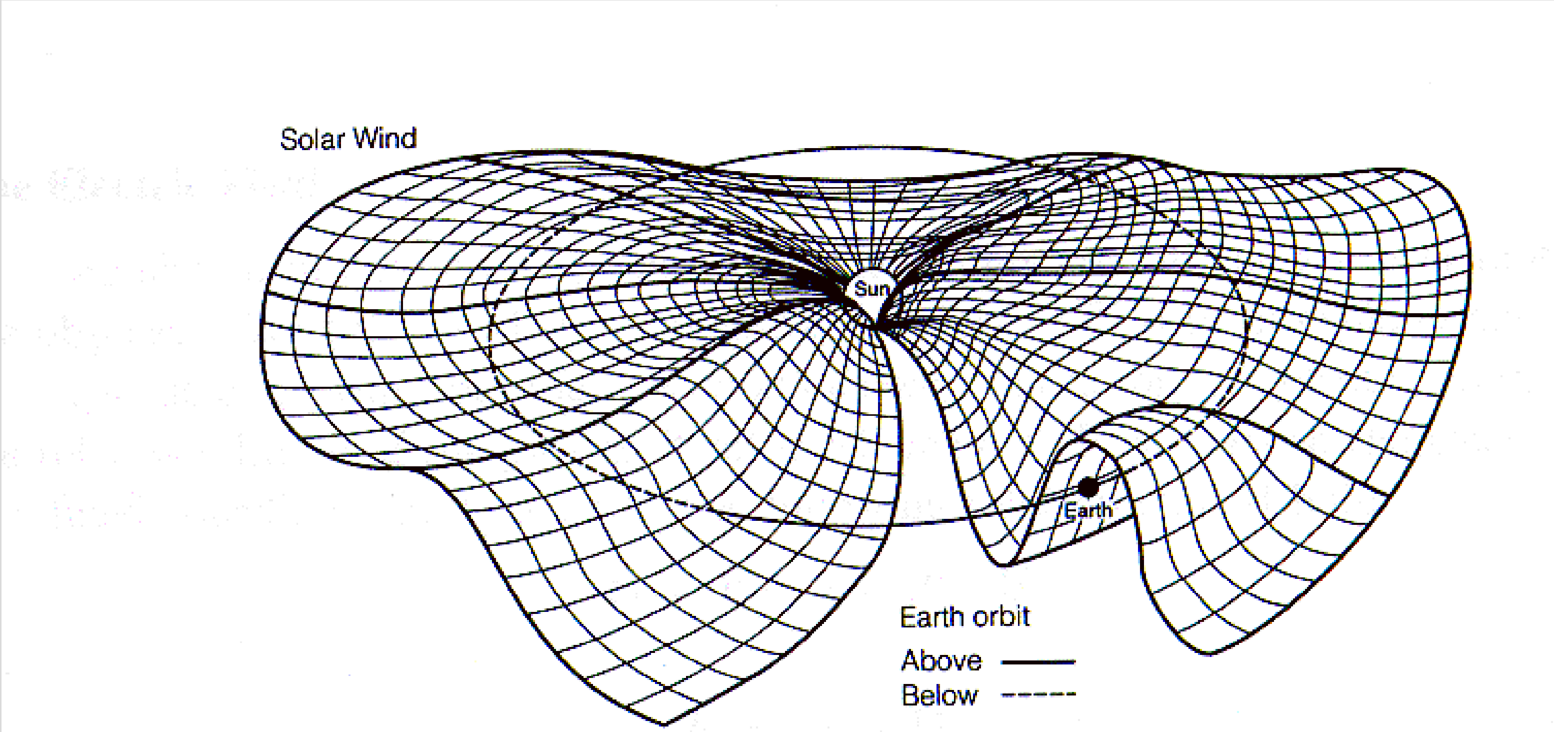
Interplanetary current sheet



$$\mu_0 \mathbf{j} = \nabla \times \mathbf{B}$$

Solar wind

Interplanetary current sheet



Later we will see that the N-S component of the interplanetary magnetic field (IMF is important for the coupling between solar wind and magnetosphere)

Solar wind

Some basic facts

Average values

$n_p = 8\ cm^{-3}$

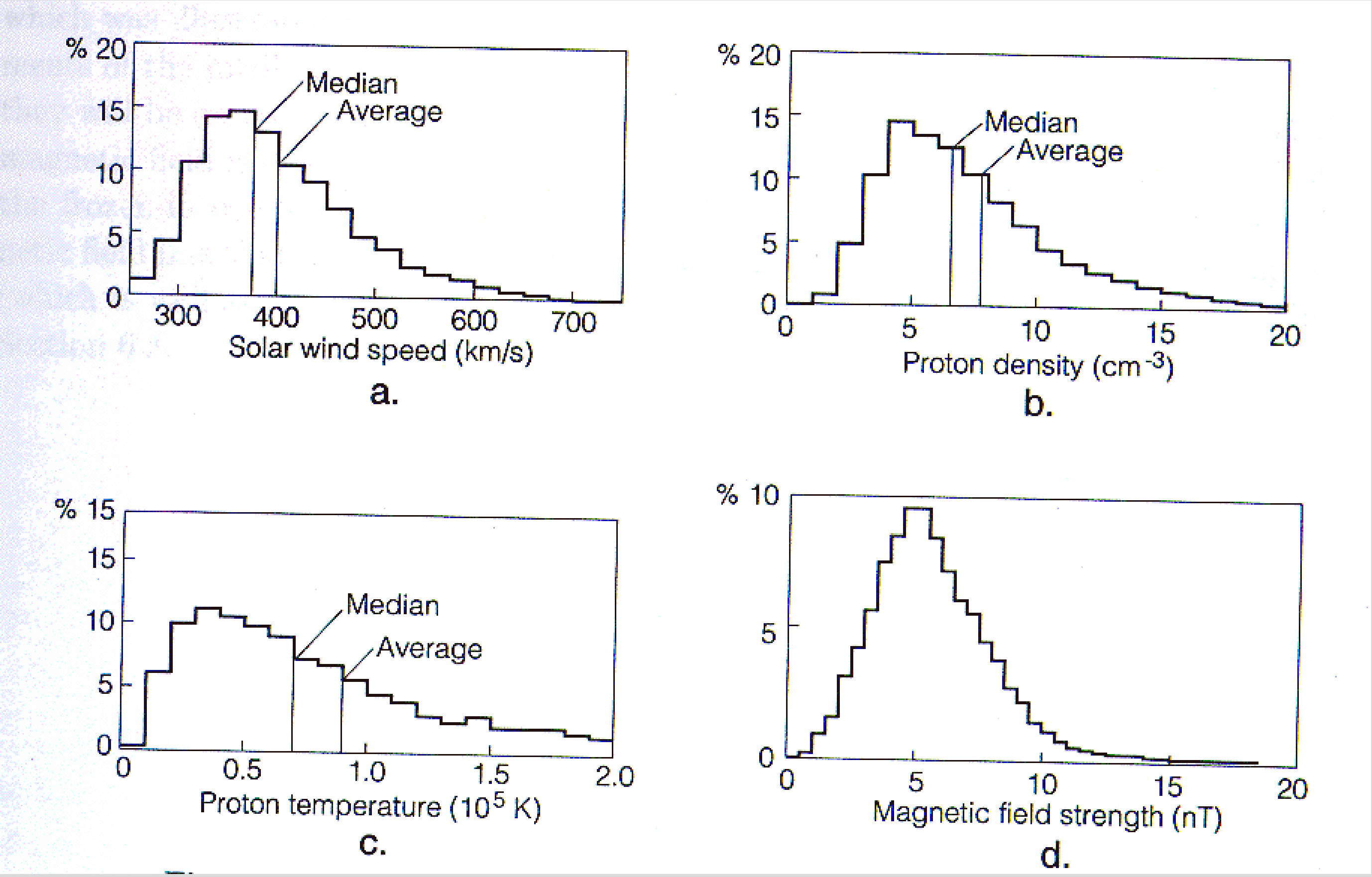
$v = 320\ km/s$

$T_p = 4 \cdot 10^4\ K$

$T_e = 10^5\ K$

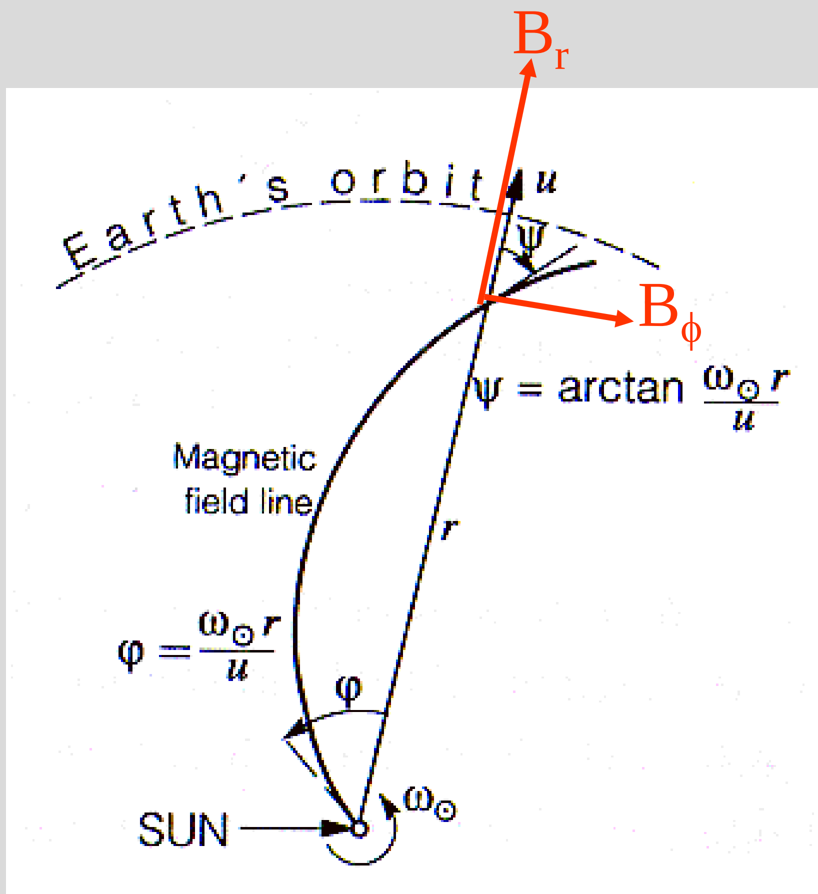
$B = 5\ nT$

$\Phi_K = \rho v^3/2 = 0.22\ mW/m^2$



Solar wind

Parker spiral



Archimedean spiral:

$$\frac{B_\phi}{B_r} = \tan\psi = \left(\frac{\omega r}{u_{SW}}\right)$$

Classification of plasmas

- **High density plasmas**
  - $\lambda << \rho$
  - *magnetic field not important, collisions dominate, isotropic.*

- **Medium density plasmas**
  - $\rho << \lambda << l_c$
  - *magnetic field important, collisions important, anisotropies.*

- **Low density plasmas**
  - $l_c << \lambda$
  - *magnetic field important, anisotropies, uninhibited motion along magnetic field*

ρ: *gyro radius*

λ: *mean free path*

l_c: *dimension of the plasma*

Plasma models/descriptions

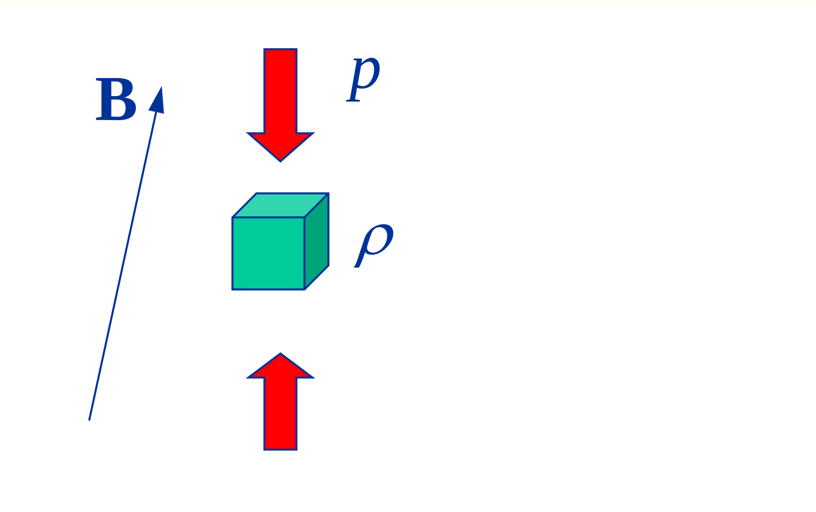
- Single particle motion
- Computer simulations of many-particle dynamics
- Generalization of statistical mechanics (kinetic theory)
- Generalization of fluid mechanics: *Magneto-hydrodynamics (MHD)*

Plasma physics
Magnetohydrodynamics (MHD)

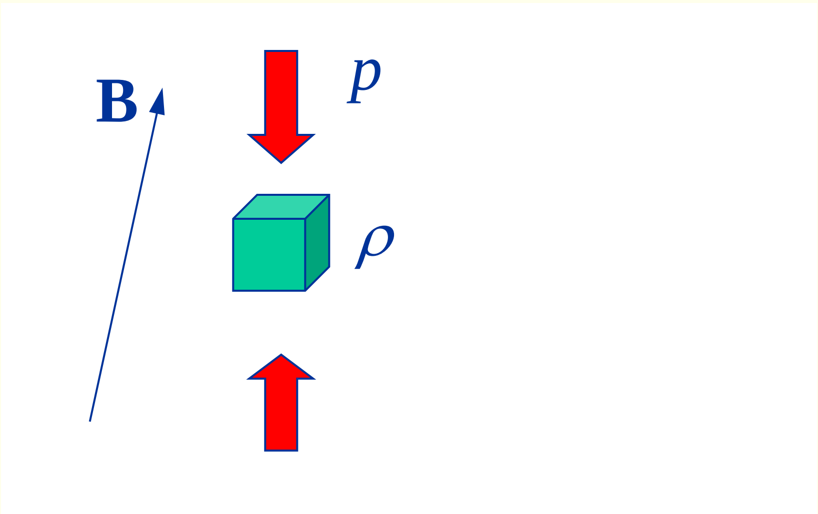
MHD is a combination of

- *fluid-/hydrodynamics* (which is based on Newton's laws of motion)
- *Maxwell's equations* (electrodynamics)

applied on a plasma volume element.



Magnetohydrodynamics (MHD)



For a volume element of plasma:

$$\mathbf{F} = m\mathbf{a} \quad \Rightarrow$$

quasineutrality

$$-\nabla p + n_e q \mathbf{v}_e \times \mathbf{B} + \rho_q \mathbf{E} = \rho \frac{d\mathbf{v}}{dt} \quad \Rightarrow$$

(1) $$\rho \frac{d\mathbf{v}}{dt} = -\nabla p + \mathbf{j} \times \mathbf{B}$$

Magnetohydrodynamics (MHD)

(1) $$\rho \frac{d\mathbf{v}}{dt} = -\nabla p + \mathbf{j} \times \mathbf{B}$$

This together with two of Maxwell's equations and Ohm's law make up the most common MHD equations:

(2) $$\mathbf{j} = \sigma(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

(3) $$\nabla \times \mathbf{B} = \mu_0 \left(\mathbf{j} + \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} \right)$$

Only consider slow variations

(4) $$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

Magnetohydrodynamics (MHD)

(1) $$\rho \frac{d\mathbf{v}}{dt} = -\nabla p + \mathbf{j} \times \mathbf{B}$$

In equilibrium:

$$0 = -\nabla p + \mathbf{j} \times \mathbf{B} \iff$$

$$-\nabla p + \frac{1}{\mu_0}(\nabla \times \mathbf{B}) \times \mathbf{B} = 0$$

$$-\nabla p - \nabla\left(\frac{B^2}{2\mu_0}\right) + \frac{1}{\mu_0}(\mathbf{B} \cdot \nabla)\mathbf{B} = 0$$

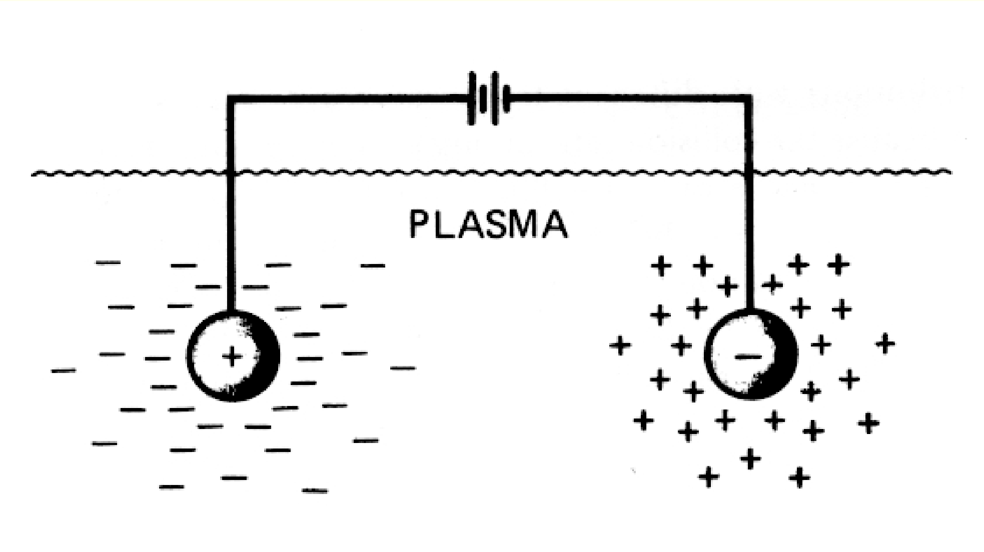
Represents tension in magnetic field

If magnetic tension = 0

$$p + \frac{B^2}{2\mu_0} = konst$$

Magnetic pressure

Quasineutrality



$$\frac{\Delta n}{n} = \frac{(n_e - n_i)}{n_e} < \left(\frac{\lambda_D}{l_c}\right)^2$$

$$\Phi = \Phi_0 e^{-x/\lambda_D}$$

Debye length

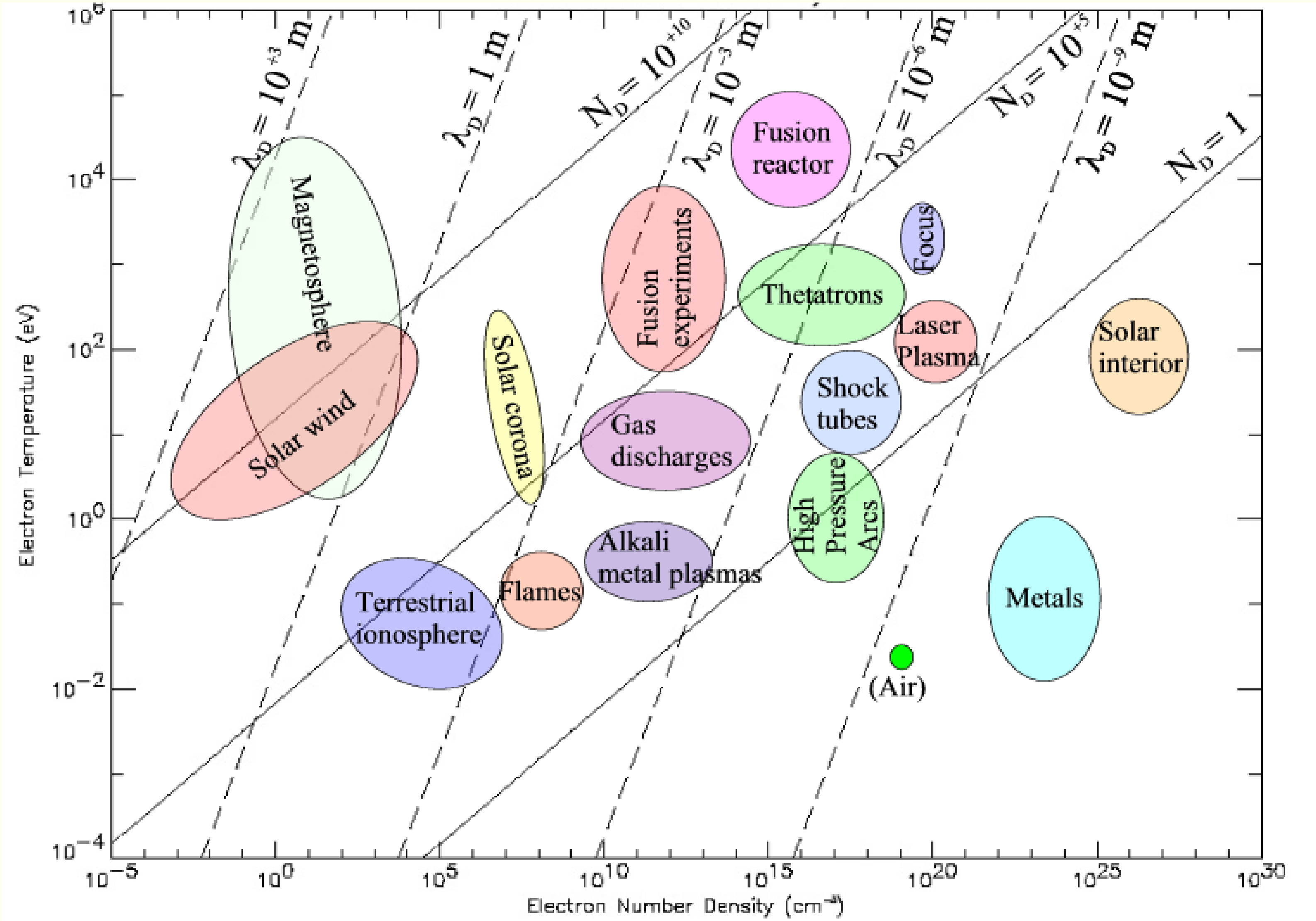
$$\lambda_D = \sqrt{\frac{\varepsilon_0 k_B T}{n_e e^2}}$$

$$l_C >> \lambda_D \quad \Rightarrow$$

Plasma close to neutral:

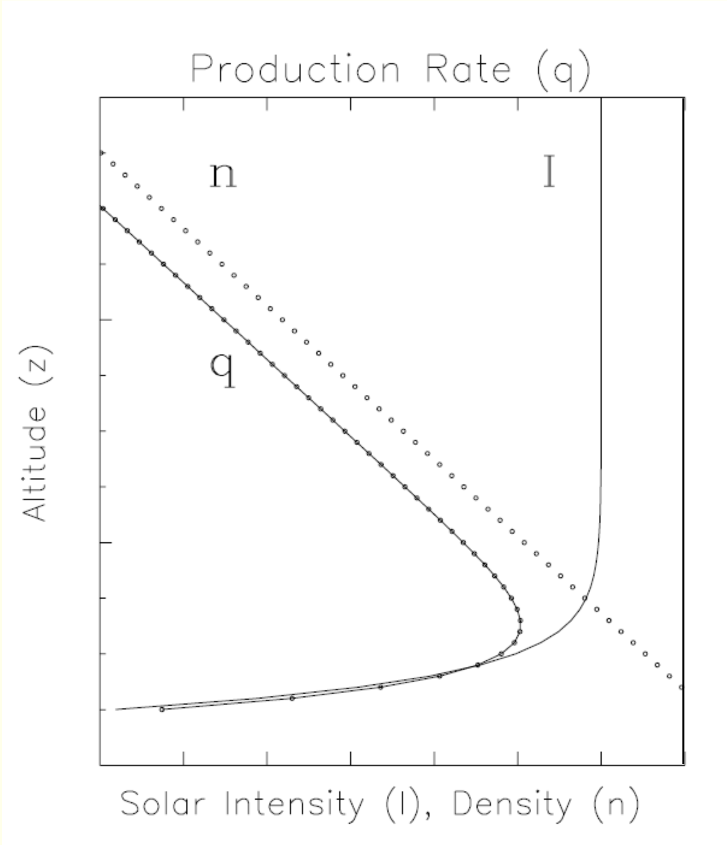
$$n_e \approx n_i$$

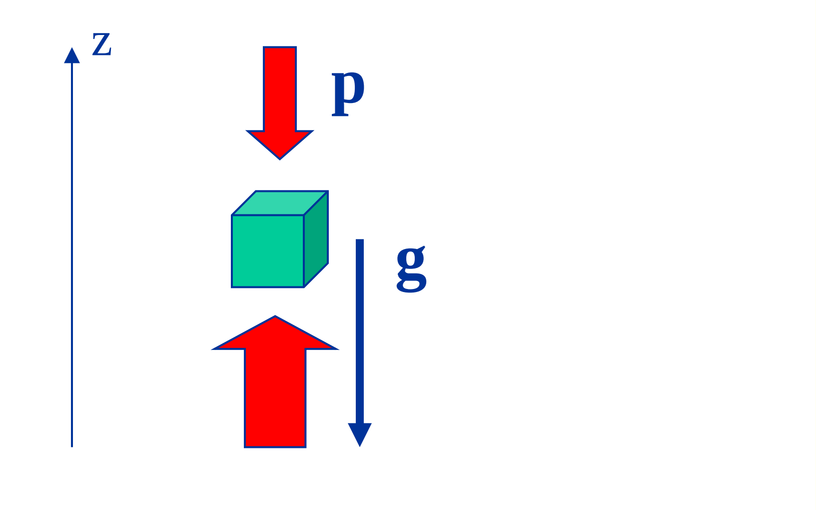
Debye lengths



The ionosphere

Basic principle for creation of ionospheric layer





Atmospheric scale height

$$-\frac{dp}{dz} = g\rho_m$$ hydrostatic equilibrium for a volume element

$$p = nk_BT = \frac{\rho k_B T}{m}$$ ideal gas law

$$-\frac{k_BT}{m}\frac{d\rho_m}{dz} = g\rho_m$$ if T is constant

$$\rho_m = const \cdot e^{-z/(k_BT/gm)} = const \cdot e^{-z/H}$$

Scale height

$H = k_BT/gm$

Scale height

$$H = k_B T/gm$$

What is the approximate scale height in the atmosphere right here, right now?

(0° C = 273 K)

Blue	1 km	Yellow	30 km
Green	9 km	Red	100 km

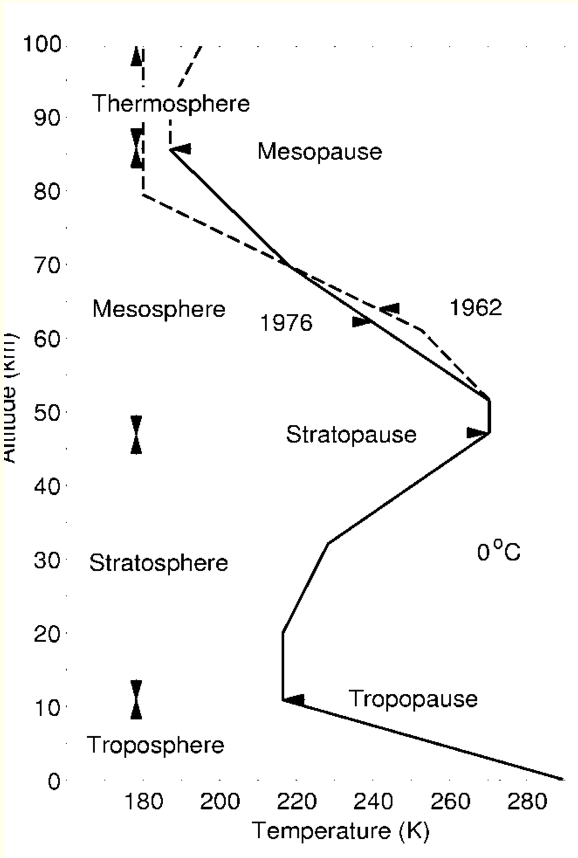
$$H = k_B T/gm = (1.38 \cdot 10^{-23} \cdot 290)/(9.81 \cdot 14 \cdot 2 \cdot 1.67 \cdot 10^{-27}) =$$

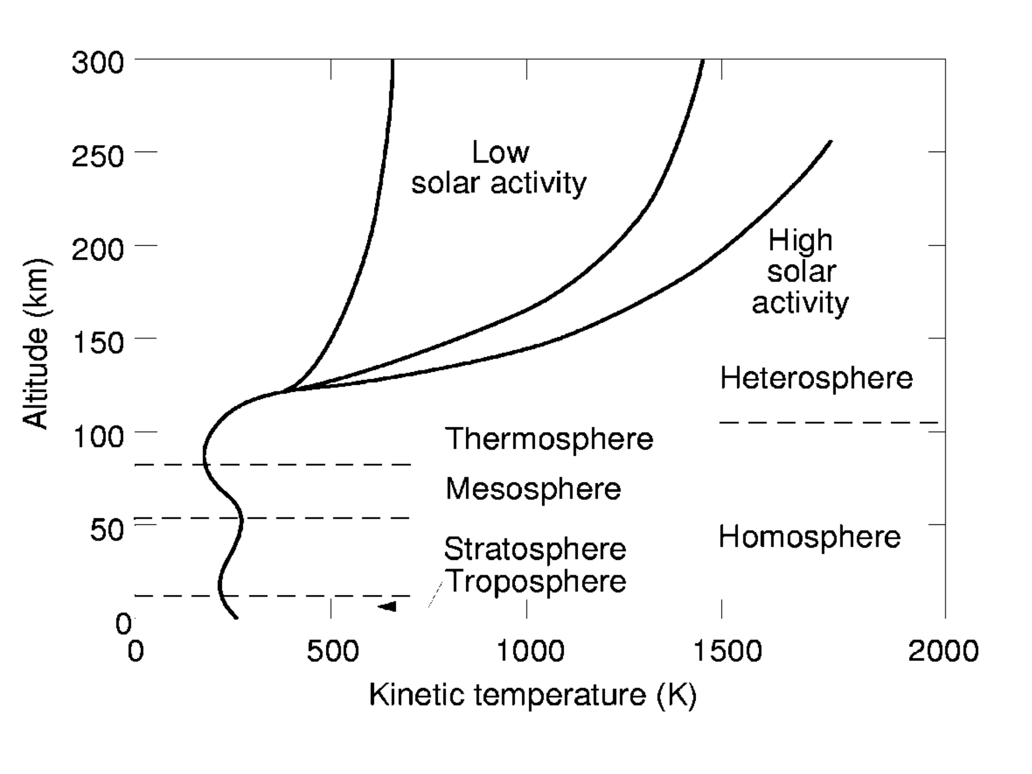
$$= 8724 \text{ m} \approx 9 \text{ km}$$

Green

What did we neglect when we derived the scale height?

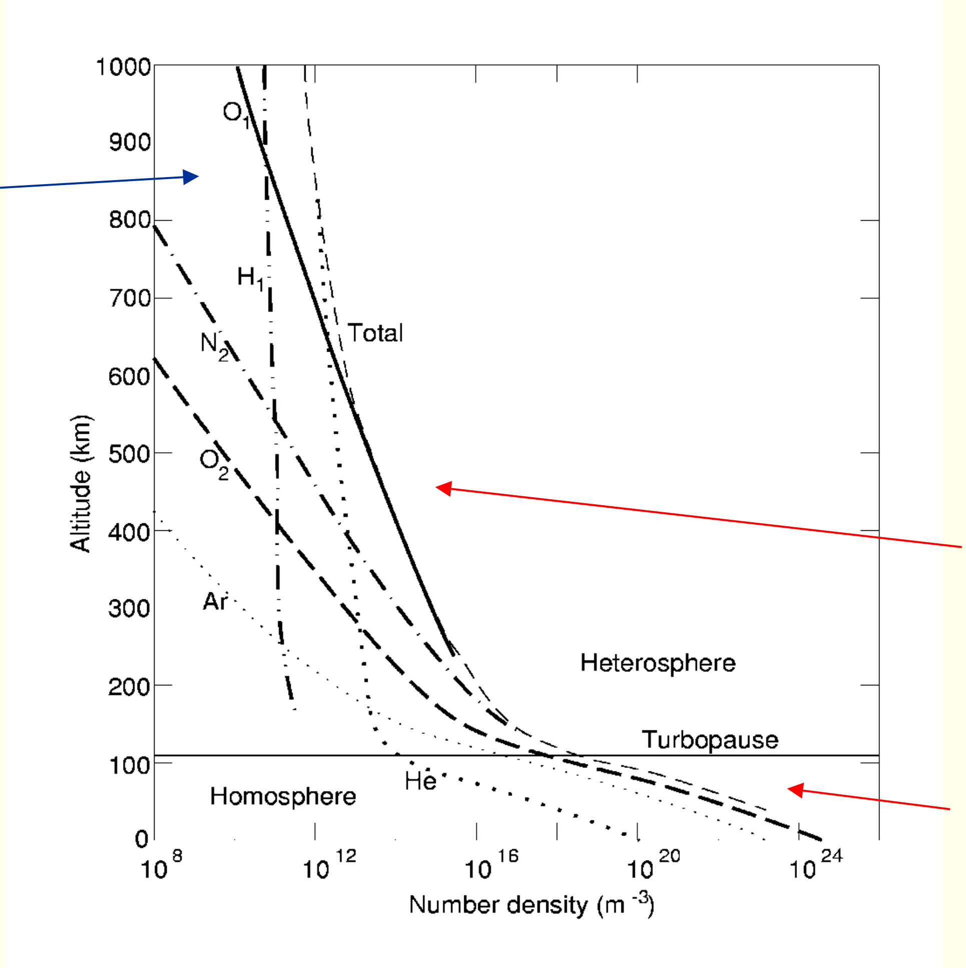
Temperature profile





Atmospheric composition

Longer scale height due to higher temperature



Separate scale heights for different components

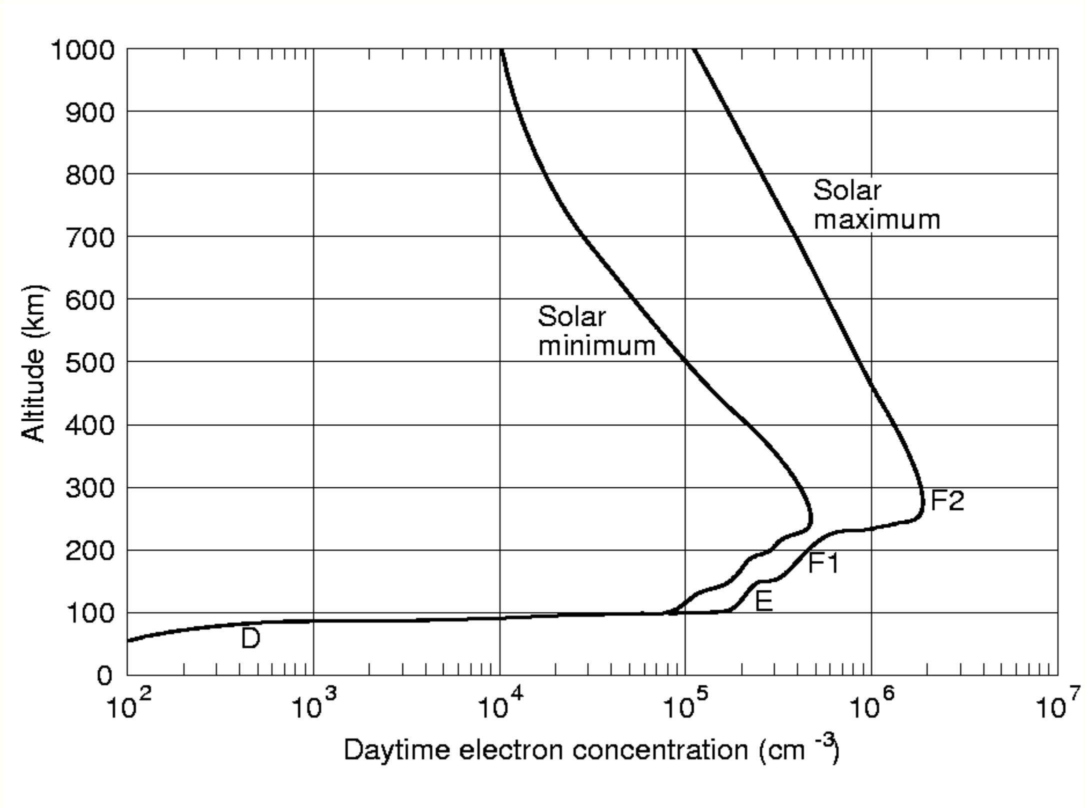
Turbulent mixing – one scale height

Ionosphere History

- The ionized, electrically conducting part of the upper atmosphere
- The ionosphere is a **plasma**

- Stewart, 1882: Explained variations in the geomagnetic field
- Kenelly & Heavyside, 1902: explained Marconis transatlantic radio communication experiments
- Appleton & Barnett: experimental proof

Altitude distribution of electron density (n_e)



Continuity equation = conservation of ?

$$\frac{\partial n_e}{\partial t} = q - r - \nabla \cdot (n_e \mathbf{v}_e)$$

Ionization ($m^{-3}s^{-1}$)

Recombination ($m^{-3}s^{-1}$)

Flow ($m^{-3}s^{-1}$)

Ionization and recombination

Continuity equation

$$\frac{dn_e}{dt} = q - r$$

$$q = a_i I n_n$$

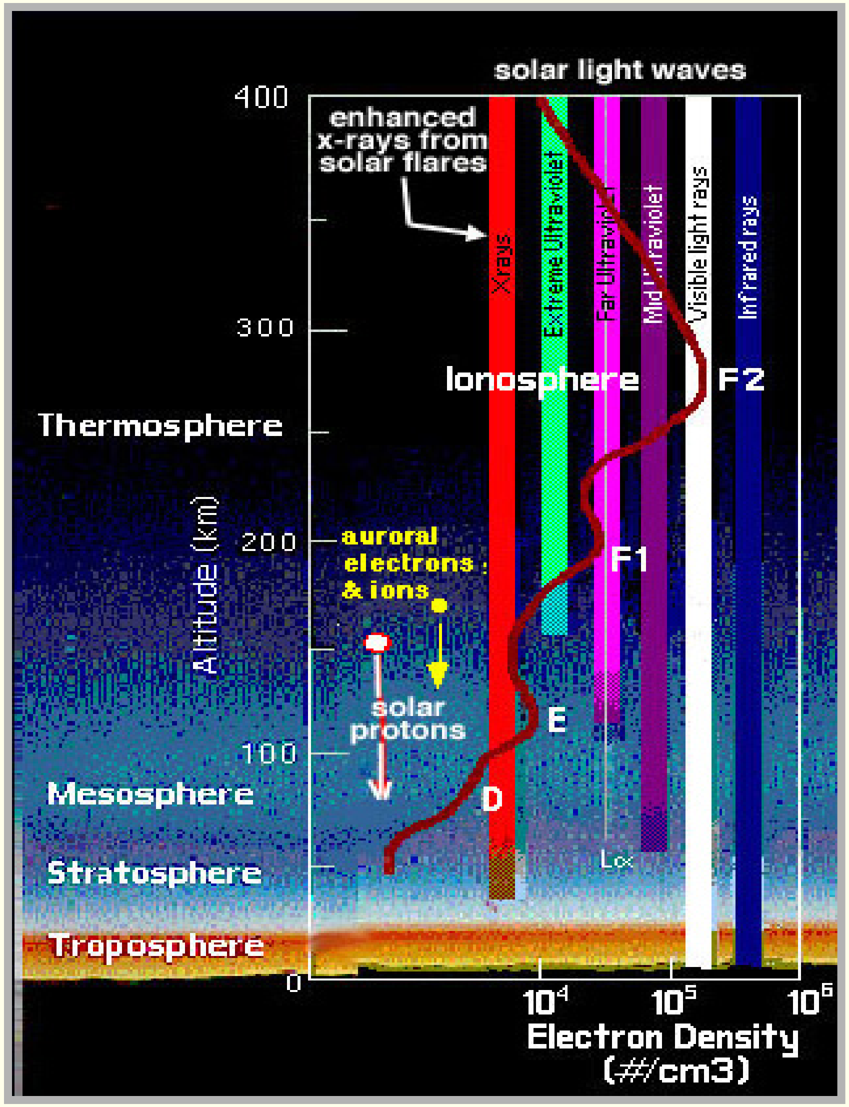
Ionization ($m^{-3}s^{-1}$)

Recombination ($m^{-3}s^{-1}$)

$$r = a_r n_e n_i = a_r n_e^2$$

Example: $e + O_2^+ \rightarrow O + O$ (dissociative recombination)

UV and X–ray radiation



$$\frac{dI}{dz} = I n_n a_a$$

Derive Chapman layer

Electron density in Chapman layer

$$n_e = \left\{ \frac{a_i}{a_r} I_0 n_0 e^{-\left(H a_a n_0 e^{-z/H} + z/H\right)} \right\}^{1/2}$$

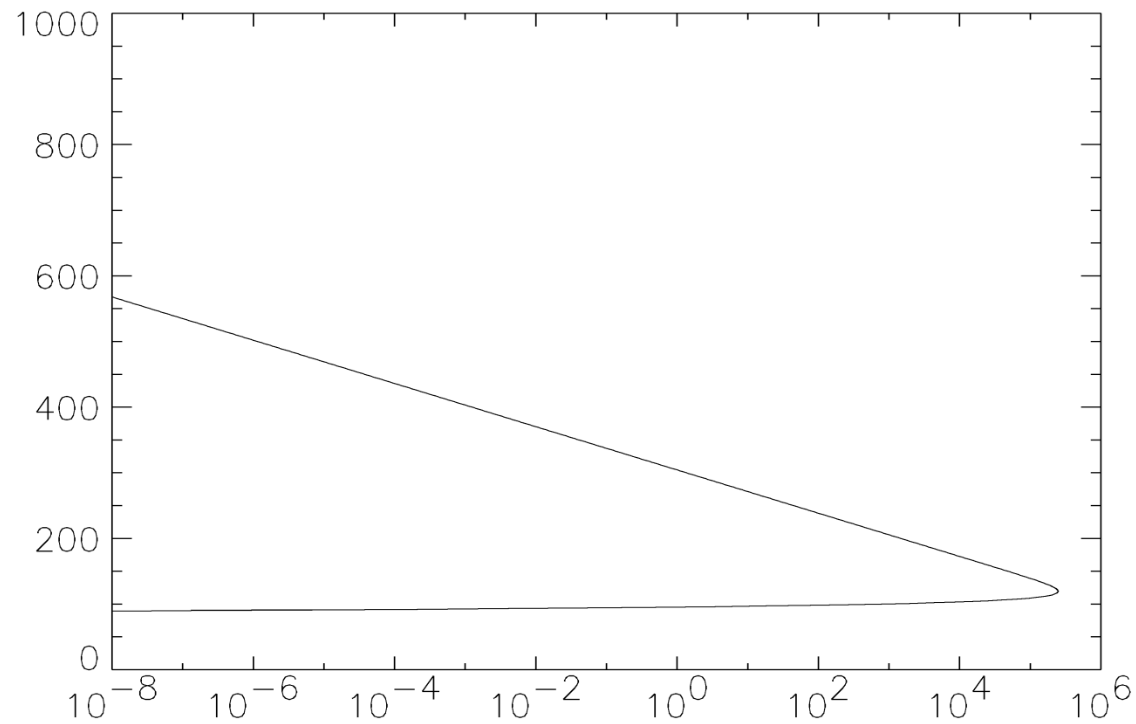
What does it look like in reality?

- Temperature not constant
- Many different wavelengths in solar radiation
- Several different molecules and atoms in neutral atmosphere. Composition also depends on altitude.

"E-region" - simple model calculation

O_2 dominating species, 10 nm X-ray radiation

$a_a = 9.3\times10^{-23}$
$a_j = 9.3\times10^{-23}$
$a_r = 3.0\times10^{-14}$
$T = 270$
$m = 16*2*amu$
$n_0 = 2.7\times10^{25}\ m^{-3}$
$I_0 = 3.6\times10^{13}$ photons/m^2/s

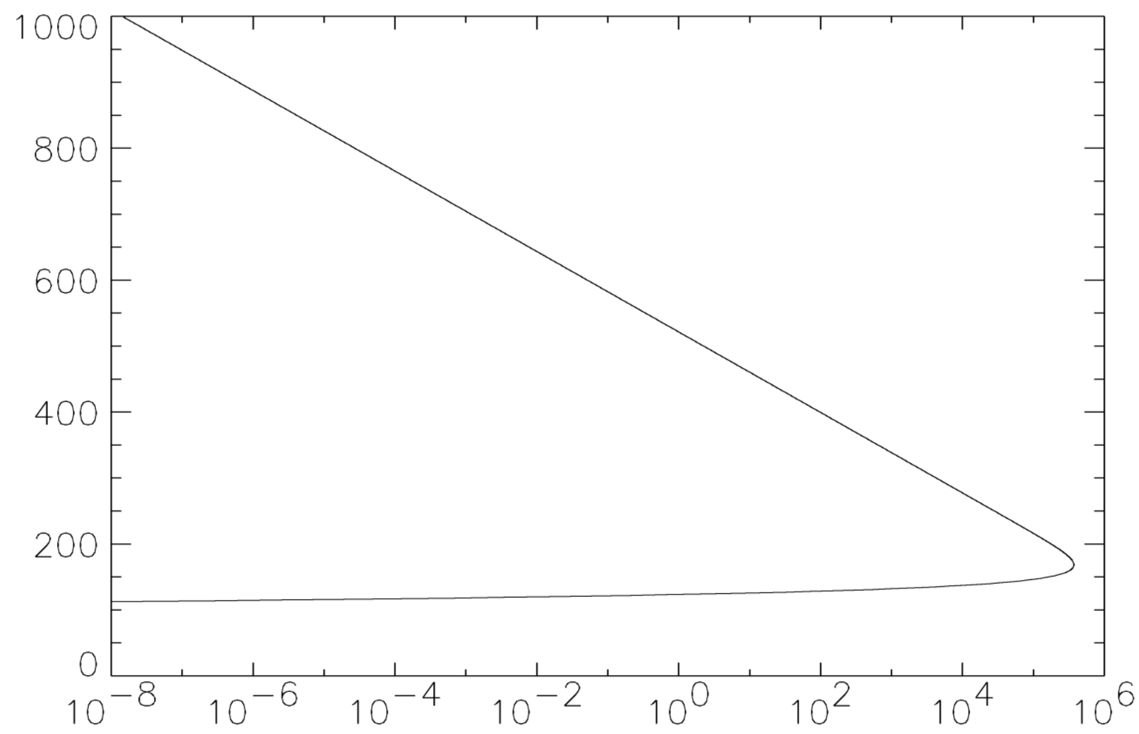


N_2^+ produced, but rapidly lost through charge exchange: $N_2^+ + O_2 \rightarrow N_2 + O_2^+$

"F1-region" - simple model calculation

O_2 dominating species, 30 nm UV radiation

$a_a = 9.3\times10^{-23}$
$a_j = 9.3\times10^{-23}$
$a_r = 3.0\times10^{-14}$
$T = 500$
$m = 16*2*amu$
$n_0 = 2.7\times10^{25}\ m^{-3}$
$I_0 = 1.5\times10^{14}$ photons/m^2/s



”F2-region” - simple model calculation

O dominating species, 30 nm UV radiation

$a_a = 9.3\times10^{-23}$

$a_j = 9.3\times10^{-23}$

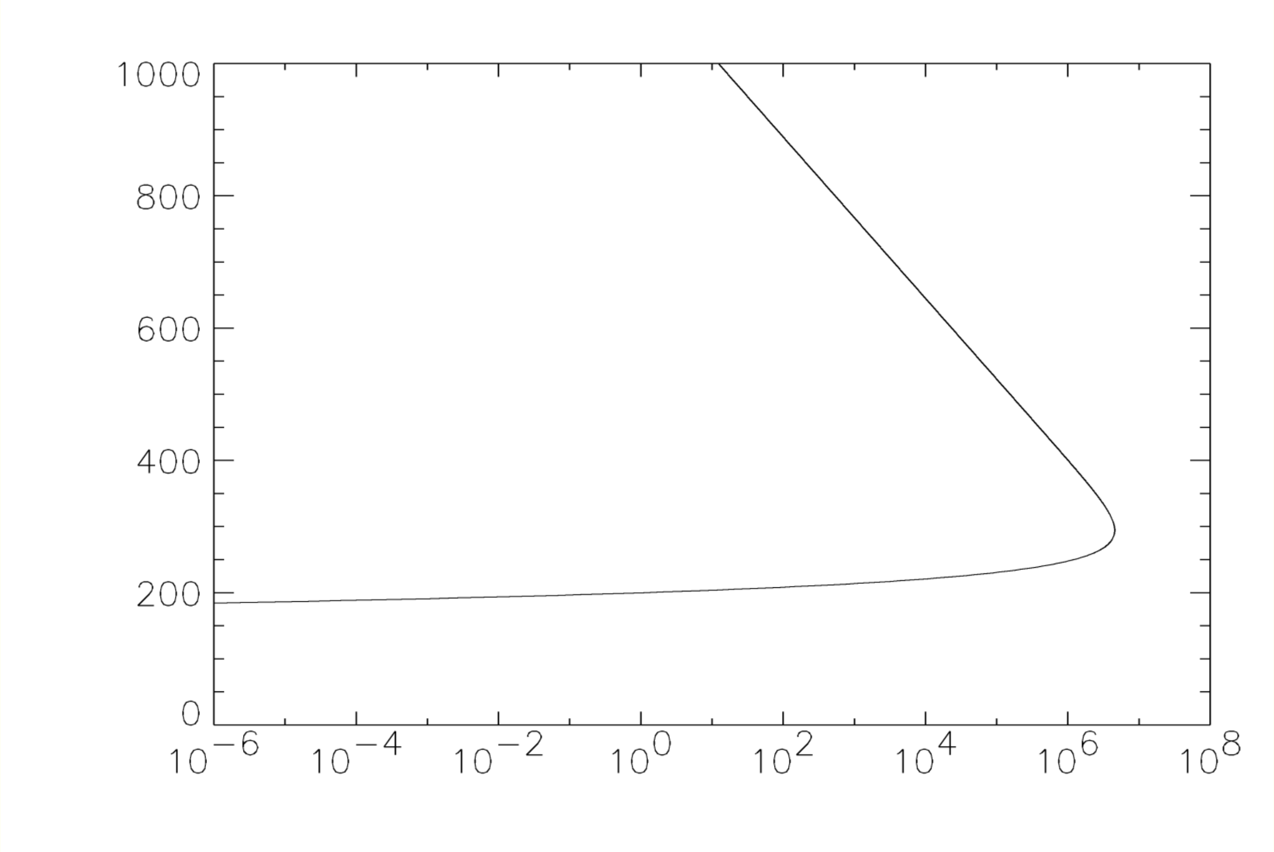
$a_r = 1.0\times10^{-16}$

$T=500$

$m = 16*amu$

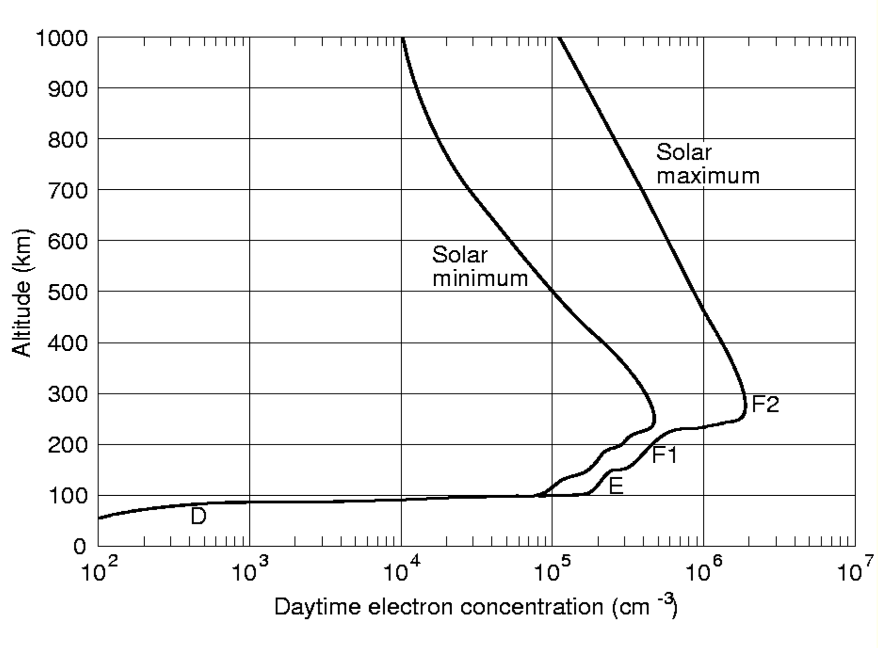
$n_0 = 2.7\times10^{25}\ m^{-3}$

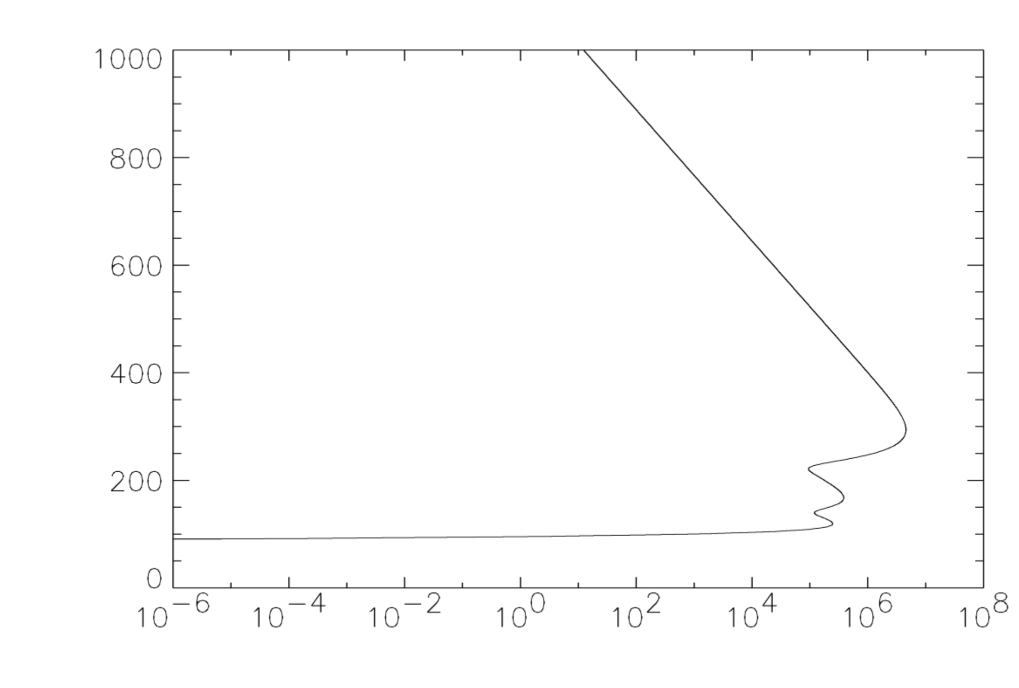
$I_0 = 1.5\ \times10^{14}$ photons/m^2/s



Measurements

”E” + ”F1” + ”F2”





Ionospheric layers

Layer	D	E	F_1	F_2
Altitude (km)	60-85	85-140	140-200	200 - ca 1500
Nighttime electron density (cm^{-3})	$<10^2$	$2 \cdot 10^3$	—	$2 - 5 \cdot 10^5$
Daytime electron density (cm^{-3})	10^3	$1 - 2 \cdot 10^5$	$2 - 5 \cdot 10^5$	$0.5 - 2 \cdot 10^6$
Ion species	NO^+ O_2^+	NO^+ O_2^+	NO^+ O_2^+ O^+	O^+ He^+ H^+
Cause of ionization	Lyman α (1215 Å) + cosmic radiation	Lyman β (1025 Å) X-rays	UV	UV

NO^+ created by chemical reaction $N_2^+ + O \rightarrow NO^+ + N$

Propation of radio waves in the ionosphere

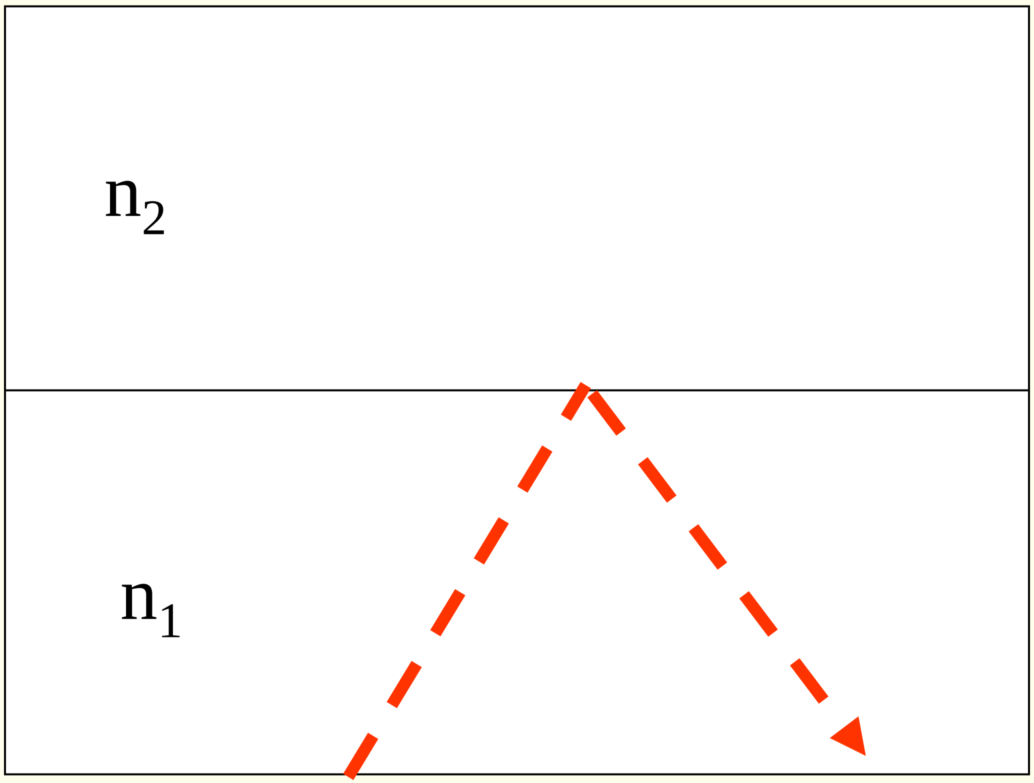
1. Absorption/damping

Takes place in the D-region due to high collision frequency. (Collisions with neutral atoms.)

2. Reflection

takes place in the F-region due to large gradients in the refraction index.

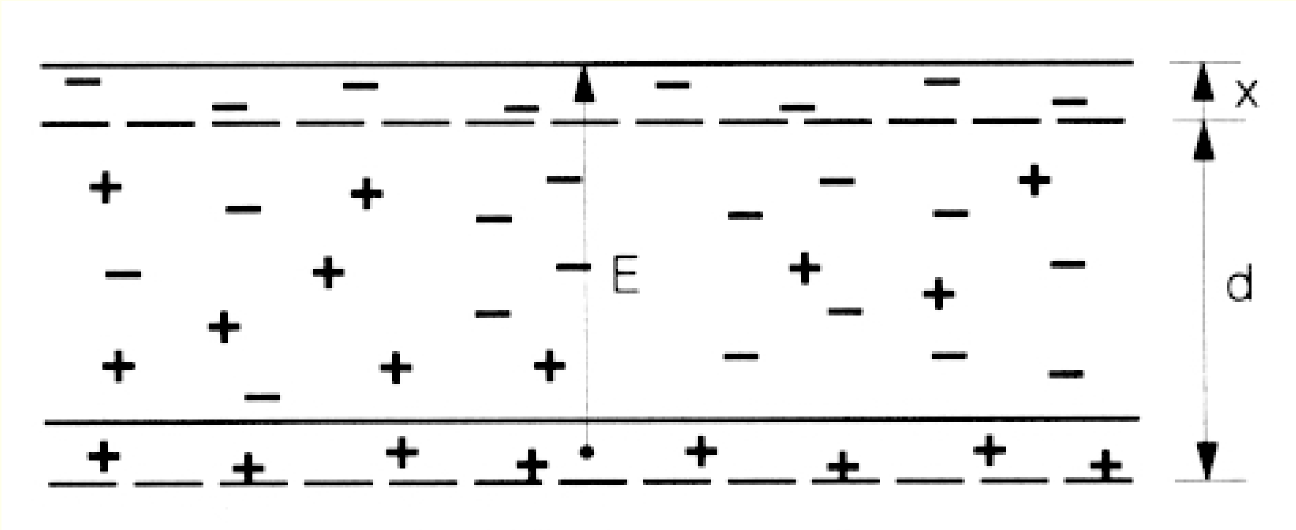
Reflection of radio waves



Total reflection at a sharp boundary (or large gradient) if

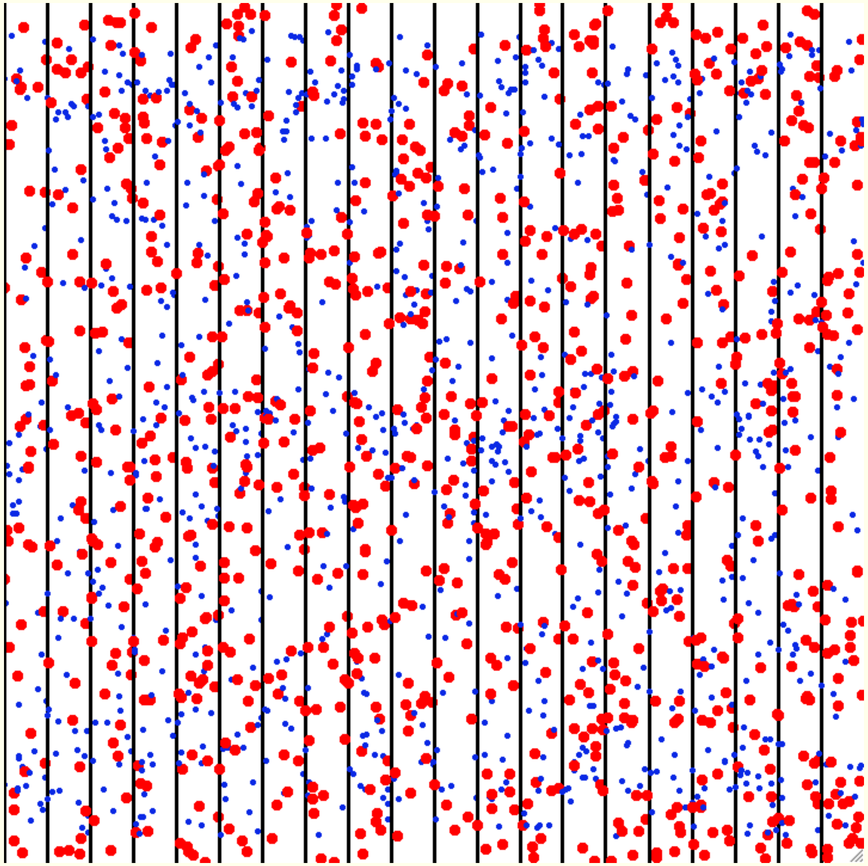
$$n_2 < n_1$$

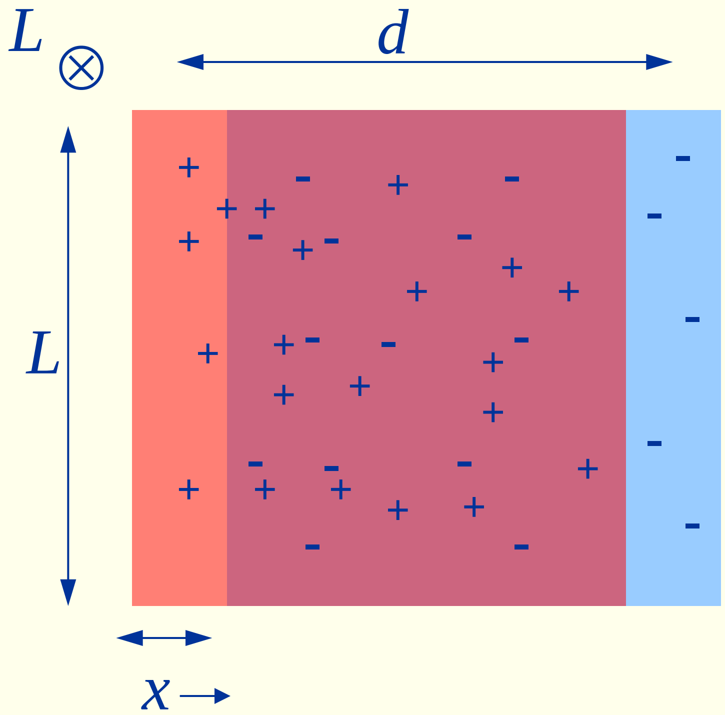
Plasma frequency



Charge imbalance creates an electric field which tends to even out the imbalance.

Plasma oscillations parallel to B





Newtons law on an individual electron inside the slab:

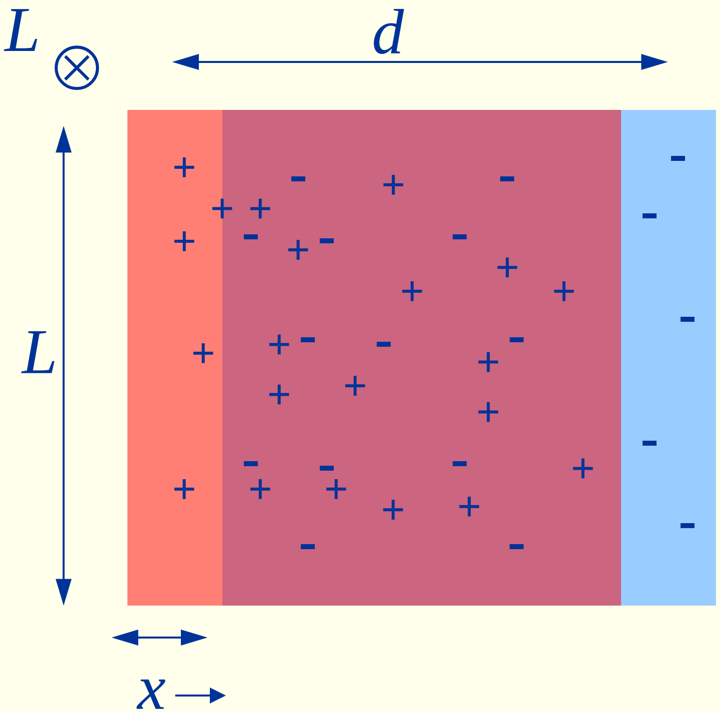
$$F = m_e a$$

$$F = -eE$$

Surface charge density

$$E = \frac{\sigma}{\varepsilon_0}$$

$$\sigma = -e n_e x$$



$$F = m_e a$$

$$F = -eE$$

$$E = \frac{\sigma}{\varepsilon_0}$$

$$\sigma = e n_e x$$

$\Rightarrow$

$$-\frac{n_e e^2 x}{\varepsilon_0 m_e} = \frac{d^2 x}{dt^2}$$

$$x = \sin(\omega_{pe} t)$$

$$\omega_{pe} \equiv \sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}}$$

What is the plasma frequency f_{pe} at the daytime E-region, close to solar minimum? (see Fälthammar p 28)

$$f_{pe} = \frac{\omega_{pe}}{2\pi} \equiv \frac{1}{2\pi}\sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}}$$

Blue	7 kHz	Yellow	400 MHz
Green	3 MHz	Red	2 GHz

$$f = \frac{\omega_{pe}}{2\pi} \equiv \frac{1}{2\pi}\sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}} = \frac{1}{2\pi}\sqrt{\frac{(1.6\cdot 10^{-19})^2}{8.854\cdot 10^{-12} 0.91\cdot 10^{-30}}}\sqrt{n_e} =$$

$$8.97\sqrt{n_e} = 8.97\sqrt{10^5\cdot 10^6} = 2.8\cdot 10^6\ Hz = 2.8\, MHz$$

Green

Index of refraction for electromagnetic waves in a plasma

(1) $$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

(2) $$\nabla \times \mathbf{B} = \mu_0 \mathbf{j} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

(3) $$\mathbf{j} = -e n_e \mathbf{v}_e$$

(4) $$m_e \frac{\partial \mathbf{v}_e}{\partial t} = -e\mathbf{E}$$

Assume all quantities vary sinusoidally, with frequency ω, *e.g.*:

$$\mathbf{E} = \mathbf{E}_0 e^{i(\mathbf{k}\cdot\mathbf{r} - \omega t)}$$

(1) $\Rightarrow$ $$\nabla \times \left(\nabla \times \mathbf{E}\right) = -\nabla \times \frac{\partial \mathbf{B}}{\partial t}$$

(2) $\Rightarrow$ $$\nabla \times \frac{\partial \mathbf{B}}{\partial t} = \mu_0 \frac{\partial \mathbf{j}}{\partial t} + \frac{1}{c^2}\frac{\partial^2 \mathbf{E}}{\partial t^2}$$

$$\therefore \quad \nabla \times \left(\nabla \times \mathbf{E}\right) = -\mu_0 \frac{\partial}{\partial t}\left(e n_e \mathbf{v}_e\right) + \frac{1}{c^2}\frac{\partial^2 \mathbf{E}}{\partial t^2}$$

$\Rightarrow$

$$\nabla\left(\nabla \cdot \mathbf{E}\right) - \nabla^2 \mathbf{E} = -\mu_0 e n_e \frac{\partial \mathbf{v}_e}{\partial t} + \frac{1}{c^2}\frac{\partial^2 \mathbf{E}}{\partial t^2}$$

$\Rightarrow$

Index of refraction for electromagnetic waves in a plasma

$$i\mathbf{k}\left(i\mathbf{k}\cdot\mathbf{E}\right)-k^2\mathbf{E}=\mu_0\left(-i\omega\right)en_e\mathbf{v}_e+\frac{1}{c^2}\left(-i\omega\right)^2\mathbf{E}$$

Does not represent E.M. wave

(4) $\Rightarrow$

$$-k^2\mathbf{E}=\mu_0\left(-i\omega\right)en_e\frac{ie\mathbf{E}}{\omega m_e}+\frac{1}{c^2}\left(-i\omega\right)^2\mathbf{E}$$

$\Rightarrow$

$$c^2k^2=-c^2\frac{\mu_0 n_e e^2}{m_e}+\omega^2=\frac{-1}{\mu_0\varepsilon_0}\frac{\mu_0 n_e e^2}{m_e}+\omega^2$$

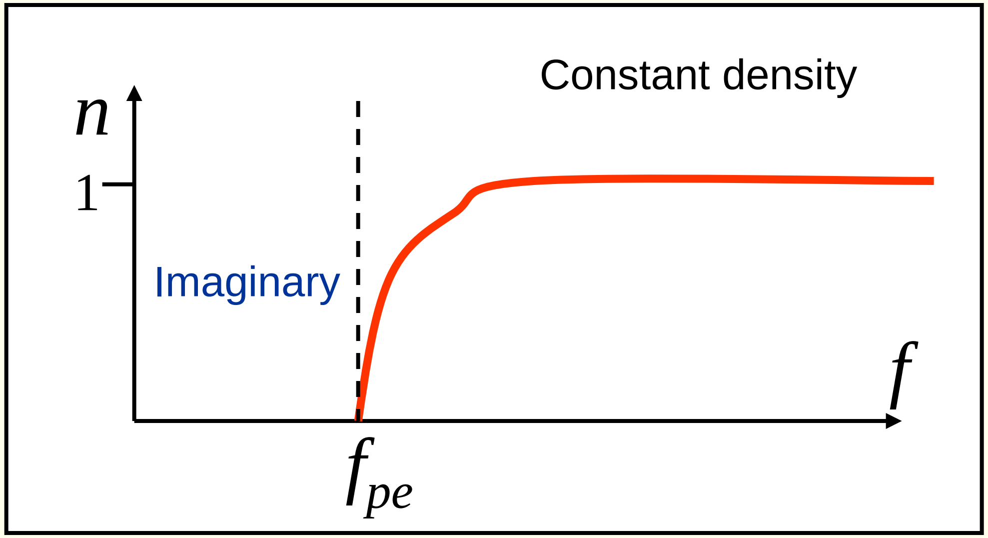
$$\therefore \quad \omega^2=c^2k^2+\omega_p^2$$

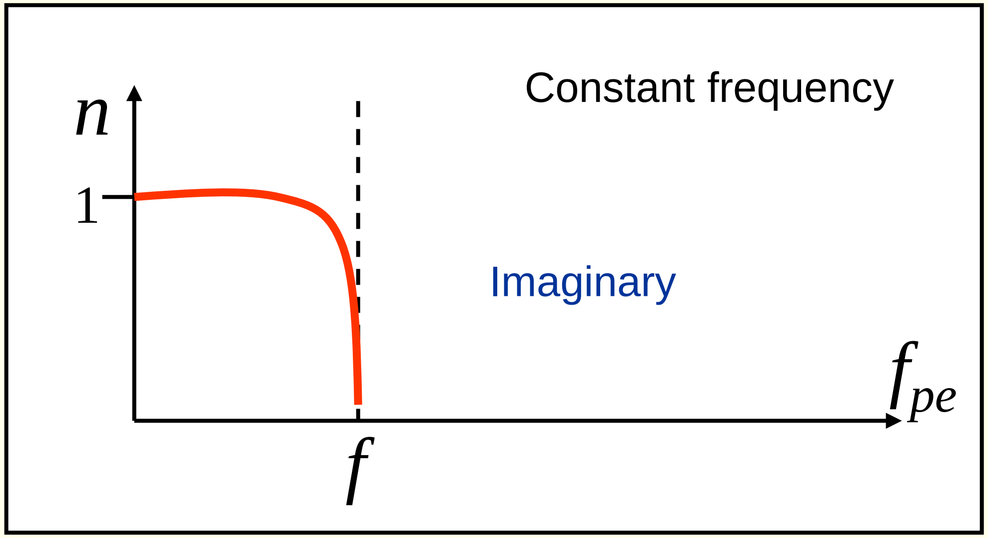
$$n^2=\frac{c^2}{v_{ph}^2}=\frac{c^2k^2}{\omega^2}=\frac{\omega^2-\omega_p^2}{\omega^2}=1-\frac{\omega_p^2}{\omega^2}$$

$\therefore$

$$n=\sqrt{1-\frac{\omega_p^2}{\omega^2}}=\sqrt{1-\frac{f_p^2}{f^2}}$$

Refraction index for plasma

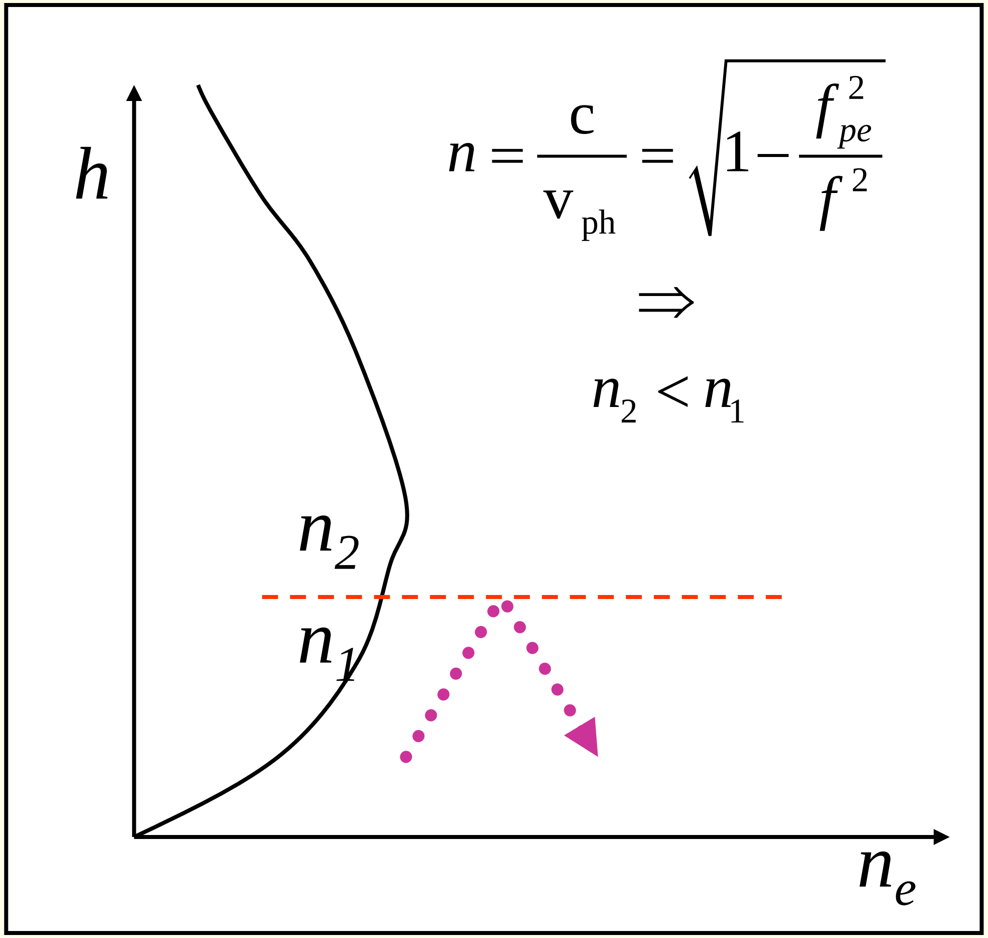




$$n = \frac{c}{v_{ph}} = \sqrt{1 - \frac{f_{pe}^2}{f^2}}$$

$$\omega_{pe} \equiv \sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}}$$

Where does the total reflection take place?

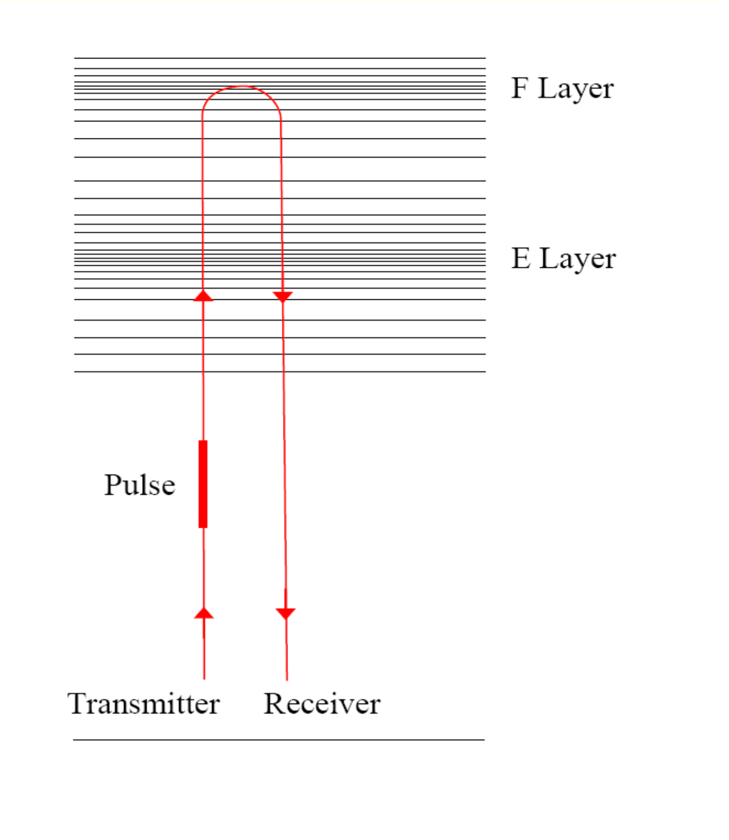


Large gradient when

$$f \approx f_{pe}$$

Higher frequencies $\rightarrow$ higher $f_{pe}\,(n_e)$

Ionosonde



The pulse will be reflected where

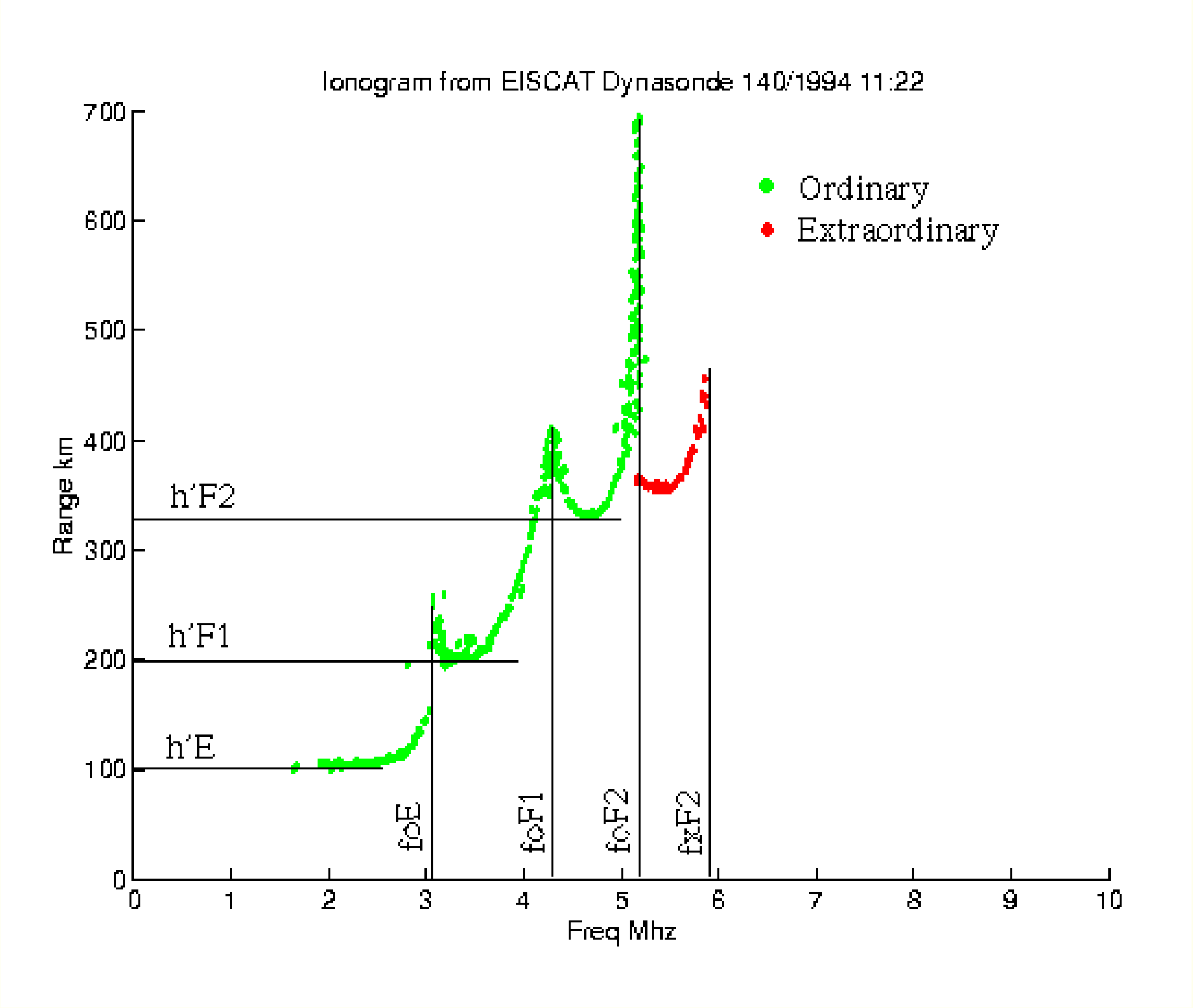
$$f = f_{pe}$$

The altitude will be determined by

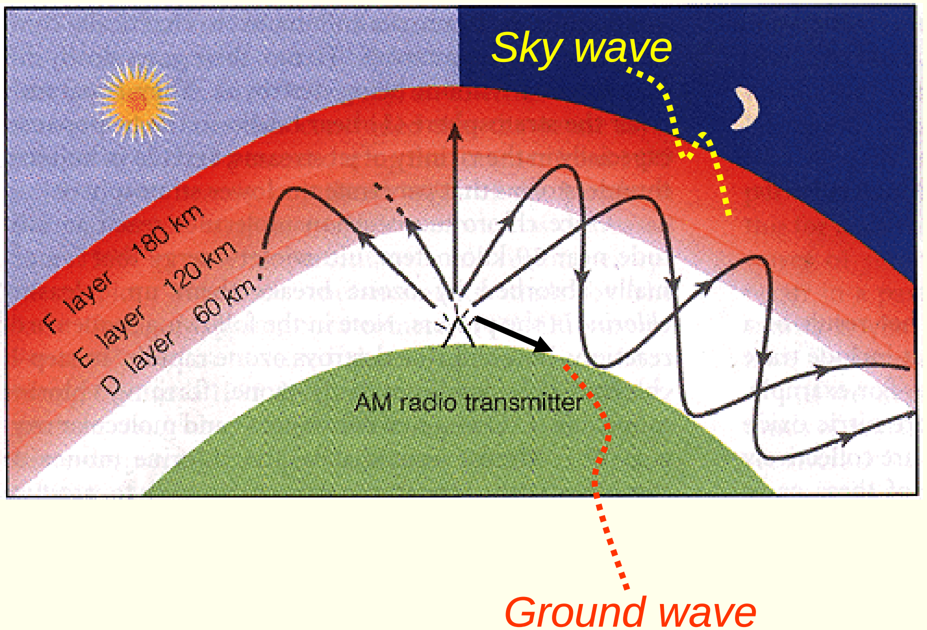
$$2h = ct$$

Where t is the time between when the pulse is sent out and the registered again.

Ionogram


Ionogram from EISCAT Dynasonde 140/1994 11:22
Ordinary
Extraordinary
Range km
700
600
500
400
300
200
100
0
h'F2
h'F1
h'E
foE
foF1
foF2
fxF2
0
1
2
3
4
5
6
7
8
9
10
Freq Mhz

Reflection of radio waves



F2-layer during night:

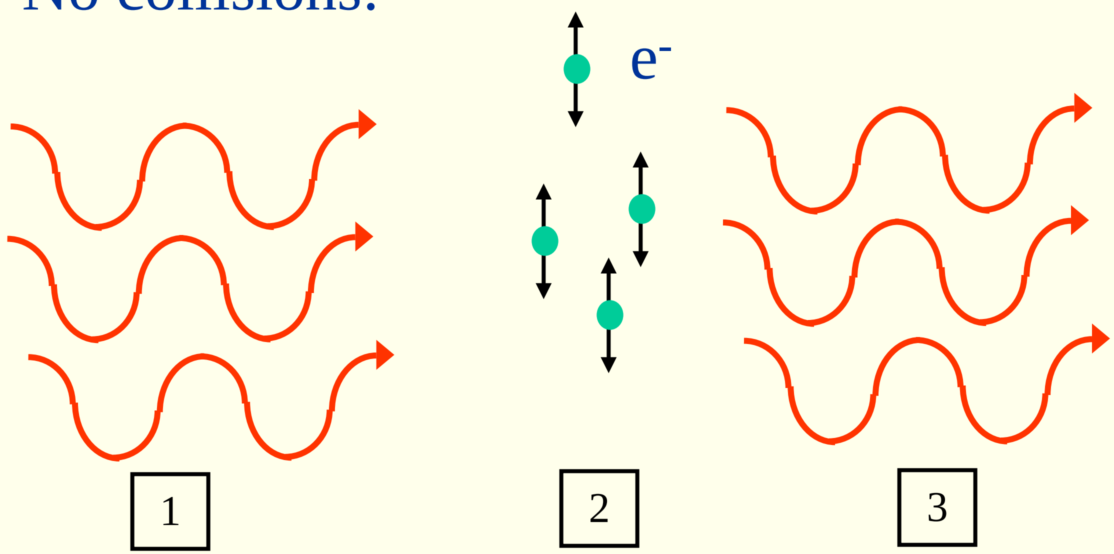
$$n_e = 5 \cdot 10^{11} \text{ m}^{-3} \quad \Rightarrow$$

$$f_{pe} = 10^7 \text{ Hz} = 10 \text{ MHz}$$

= HF/short wave

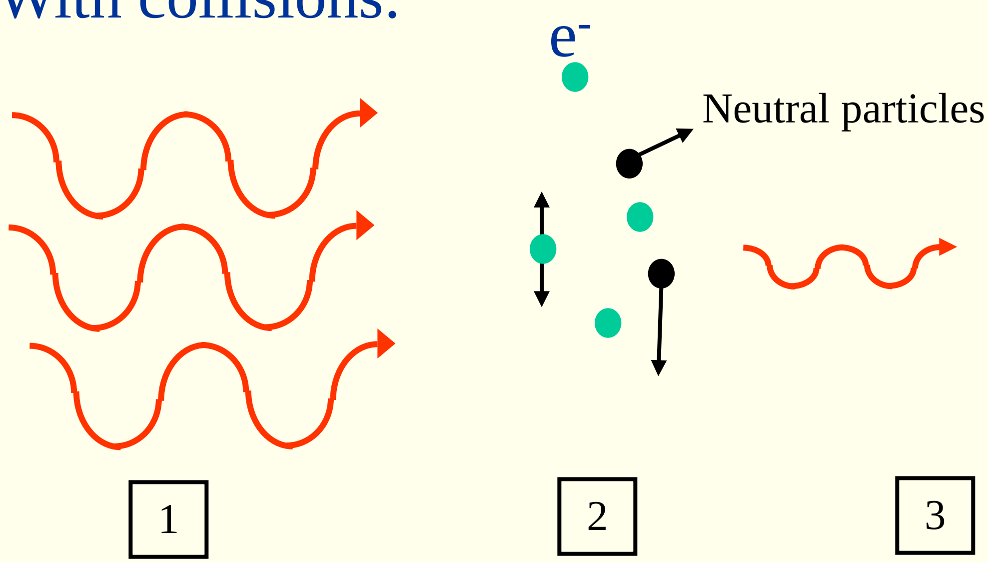
Absorption of radio waves

No collisions:



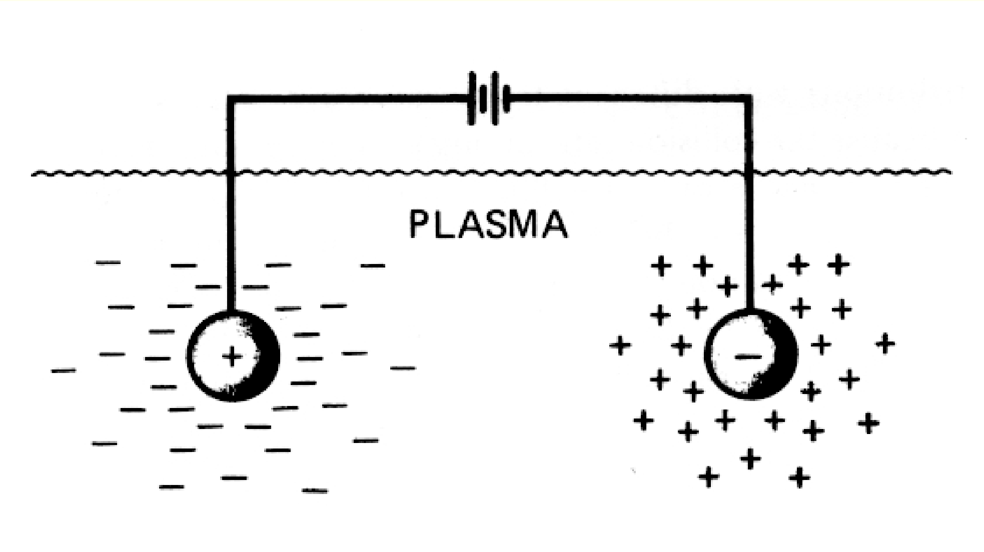
Absorption of radio waves

With collisions:



Last Minute!

Quasineutrality



$$\Phi = \Phi_0 e^{-x/\lambda_D}$$

Debye length

$$\lambda_D = \sqrt{\frac{\varepsilon_0 k_B T}{n_e e^2}}$$

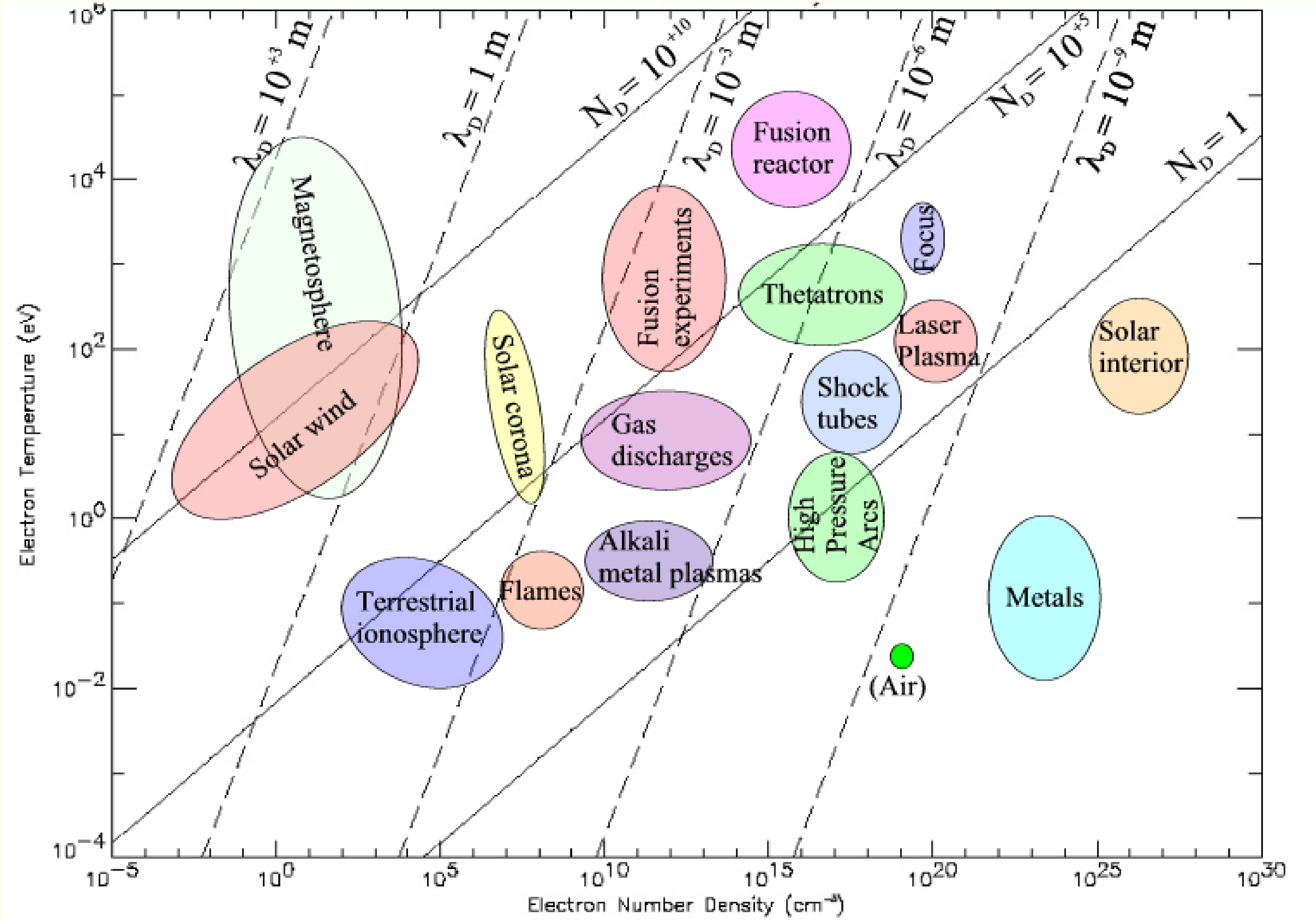
$$\frac{\Delta n}{n} = \frac{(n_e - n_i)}{n_e} < \left(\frac{\lambda_D}{l_c}\right)^2$$

$$l_C >> \lambda_D \quad \Rightarrow$$

Plasma close to neutral:

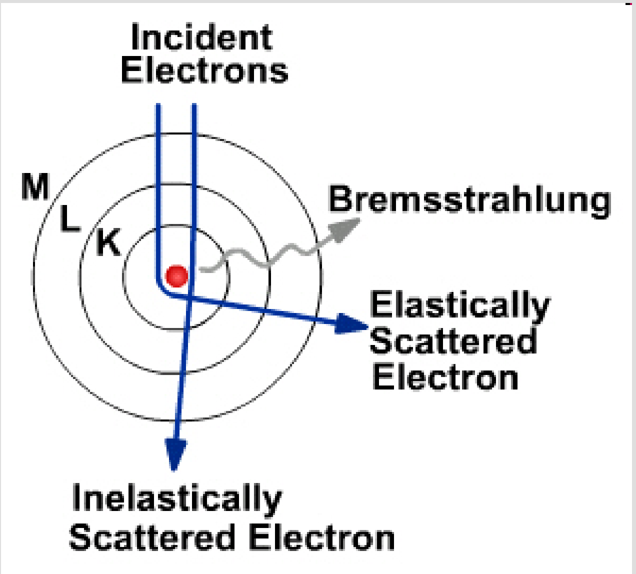
$$n_e \approx n_i$$

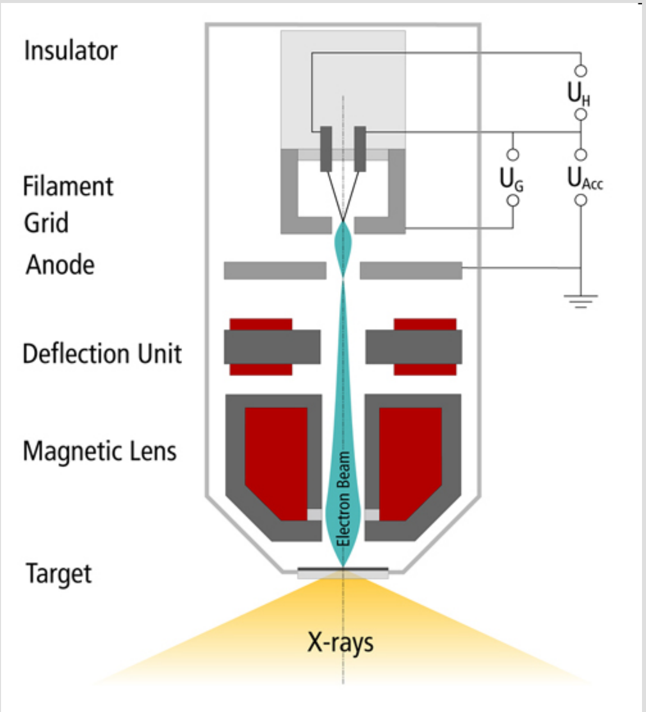
Debye lengths

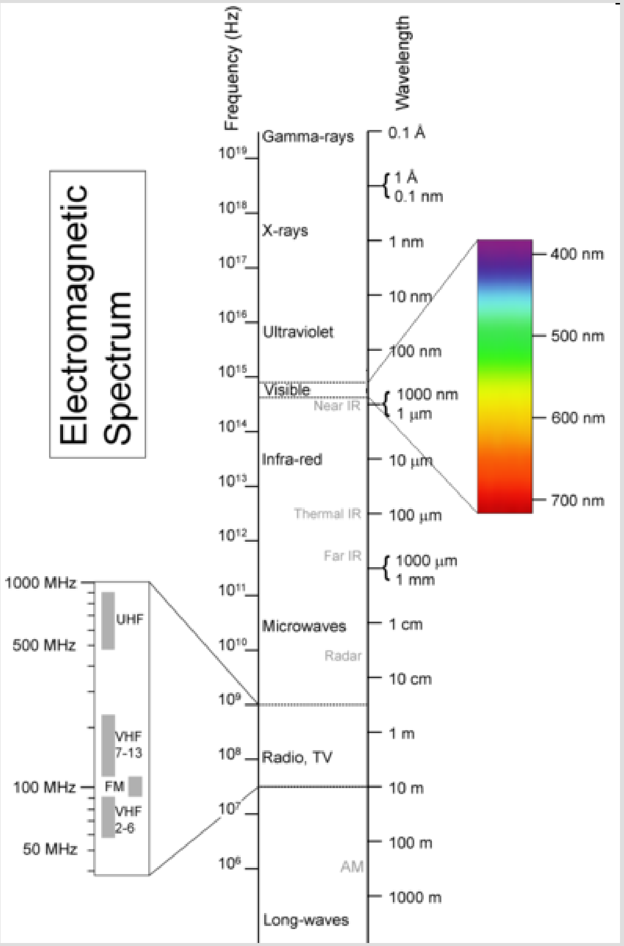


KTH
VETENSKAP
OCH KONST

X-rays, Bremsstrahlung







$$U_{acc} = hf = \frac{hc}{\lambda} \quad \Rightarrow$$

$$\lambda = \frac{hc}{U_{acc}} = \frac{6.62 \cdot 10^{-34} \cdot 3 \cdot 10^{8}}{100 \cdot 10^{3} \cdot 1.6 \cdot 10^{-19}} = 1.2 \cdot 10^{-11}\,\mathrm{m} = 0.012\,\mathrm{nm}$$