# Last lecture (5)

- Ionosphere
  - index of refraction
  - reflection of radio waves
  - particle drift motion in magnetized plasma
  - electrical conductivity in ionosphere

# Today’s lecture (6)

- Magnetosphere, introduction
- Magnetospheric size (standoff distance)
- Particle motion in the magnetosphere

# 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 | | |

Sign up for the exam on My Pages (before Oct 14)

(Make sure you are registered. If you are not, contact stex@ee.kth.se)

# EF22445 Space Physics II
# 7.5 ECTS credits, P2

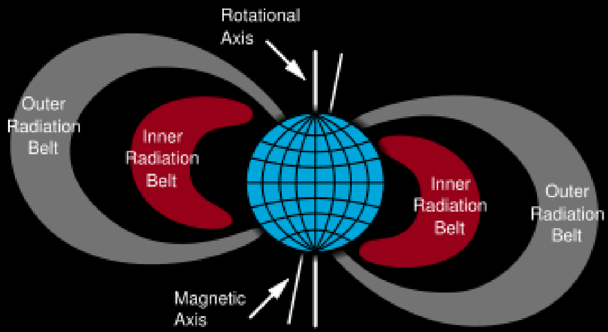
- shocks and boundaries in space
- solar wind interaction with magnetized and unmagnetized bodies
- reconnection
- sources of magnetospheric plasma
- magnetospheric and ionospheric convection
- auroral physics
- storms and substorms
- global oscillations of the magnetosphere

# Courses at the Alfvén Laboratory

## EF2260 SPACE ENVIRONMENT AND SPACECRAFT ENGINEERING , 6 ECTS credits, period 2

- environments spacecraft may encounter in various orbits around the Earth, and the constraints this places on spacecraft design
- basic operation principles underlying the thermal control system and the power systems in spacecraft
- measurements principles in space

*The Astrid-2 satellite*




*Radiation environment in near-earth space*

### Projects:

- Design power supply for spacecraft
- Study of radiation effects on electronics

# Index of refraction for electromagnetic waves in a plasma (corrected)

(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 $\omega$, *e.g.*:

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

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

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

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

$\Rightarrow$

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

$\Rightarrow$

# Index of refraction for electromagnetic waves in a plasma (corrected)

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

Does not represent E.M. wave

(4) ⇨

$$k^2\mathbf{E}=-\mu_0 en_e\frac{e\mathbf{E}}{m_e}+\frac{1}{c^2}\omega^2\mathbf{E}$$

⇨

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

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

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

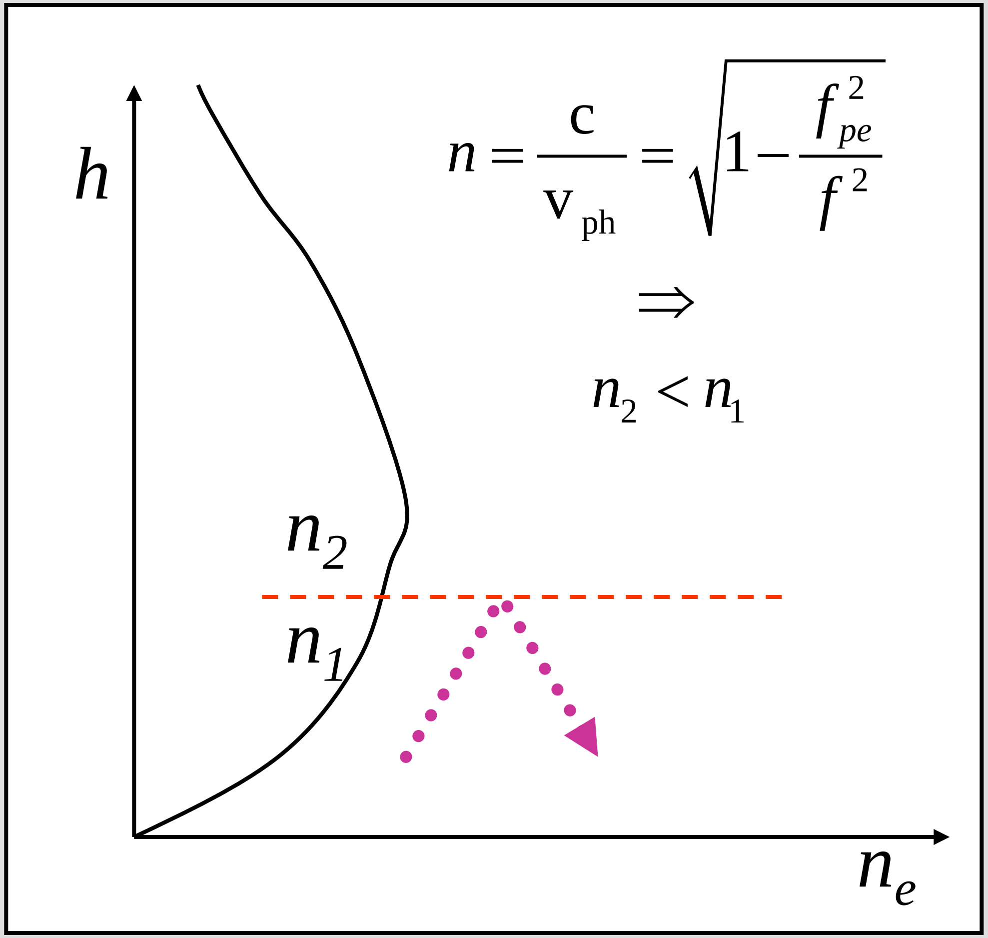
$$\therefore$$

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

# Where does the total reflection take place?

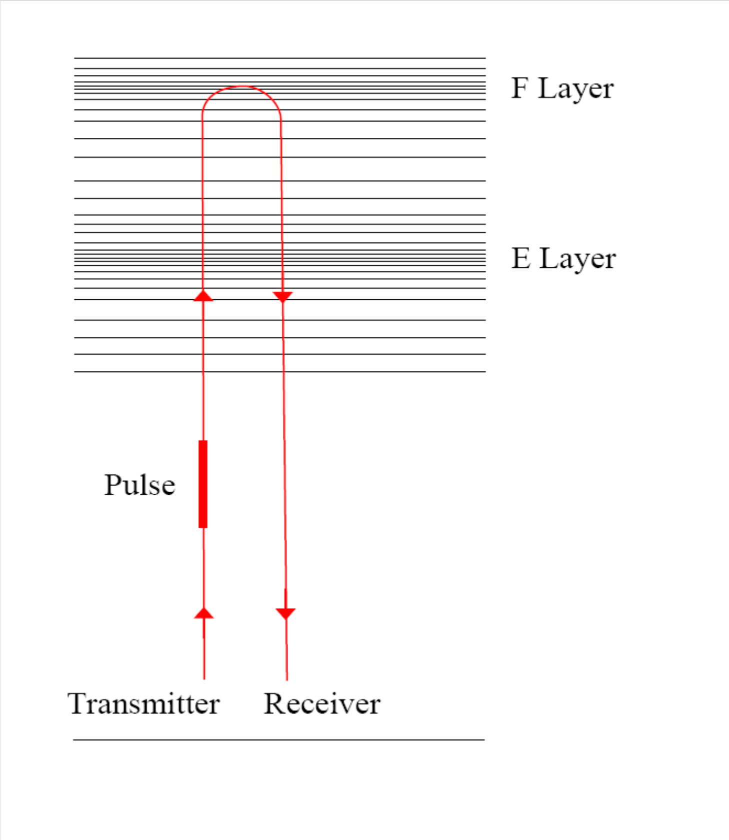
Large gradient when

$$f \approx f_{pe}$$




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

# Ionosonde




The pulse will be reflected where

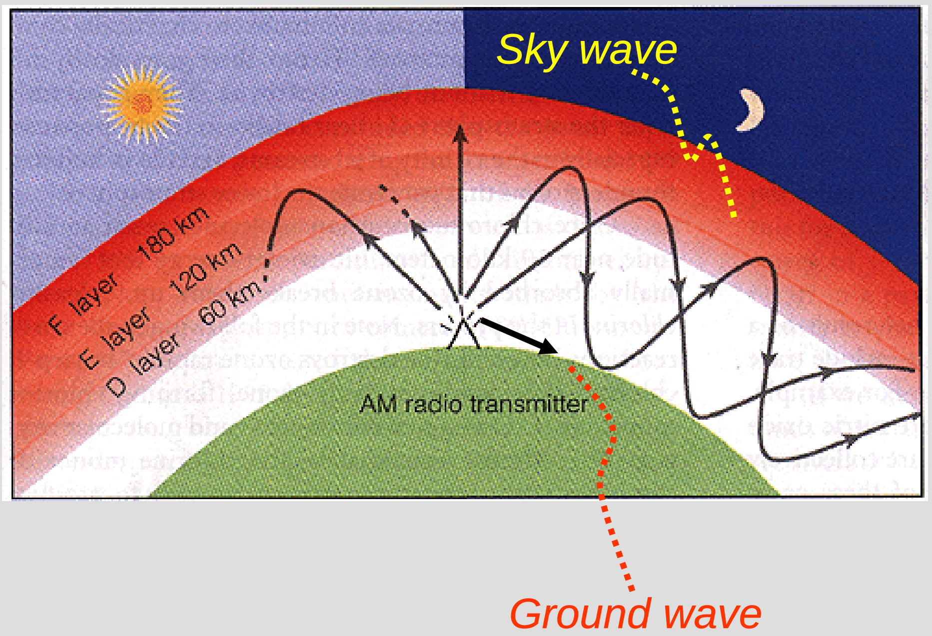
$$f = f_{pe}$$

The altitude will be determined by

$$2h = ct$$

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

# Reflection of radio waves

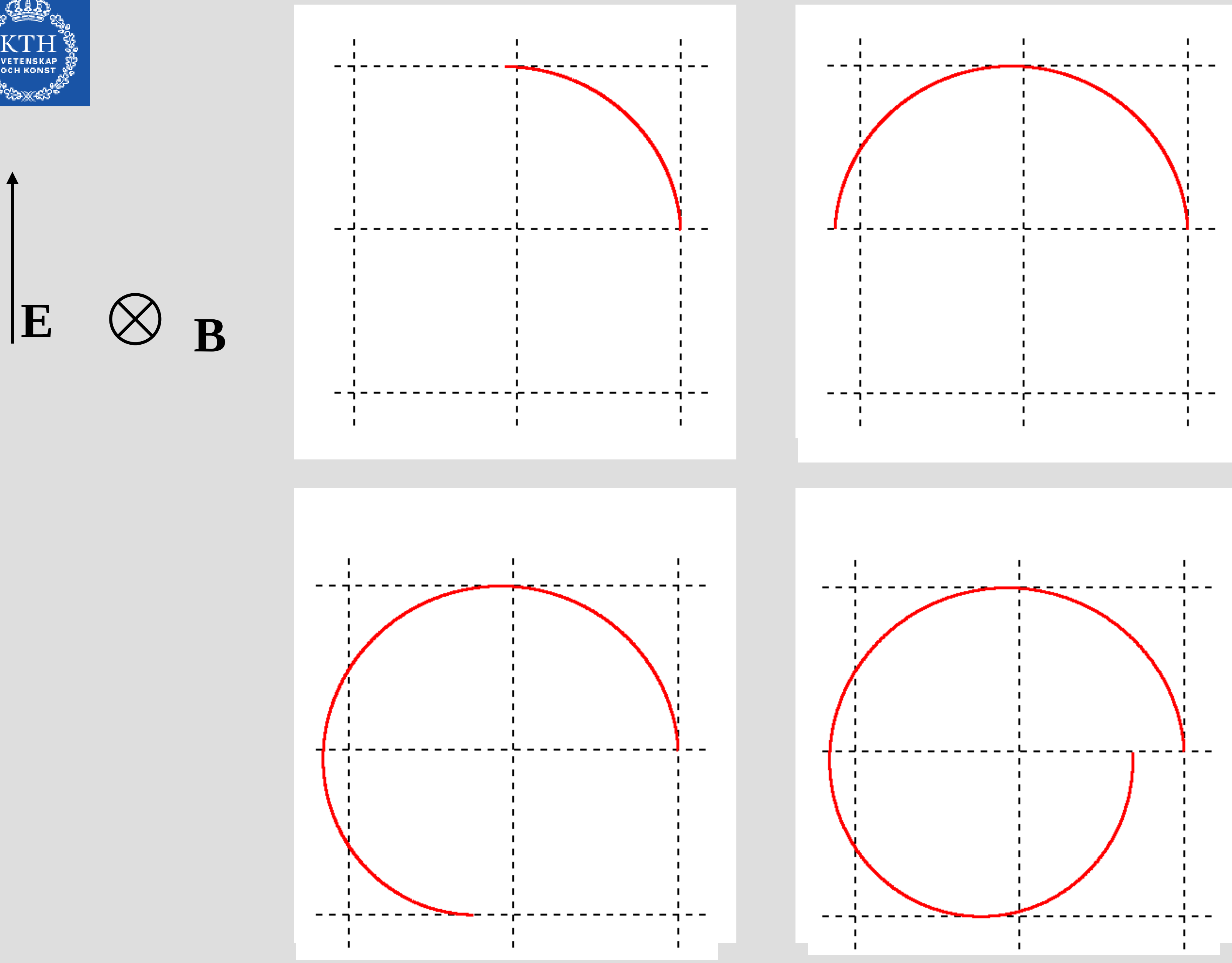



*F2-layer during night:*

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

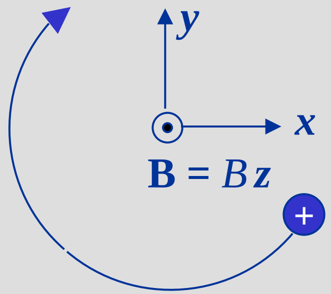
$$f_{pe} = 10^7\ \mathrm{Hz} = 10\ \mathrm{MHz}$$

= HF/short wave


E
B

# Drift motion

Consider a charged particle in a magnetic field.




Assume an electric field in the x-z plane:

$$\mathbf{E} = \left( E_x, 0, E_z \right)$$

$$m\frac{d\mathbf{v}}{dt} = q\left( \mathbf{v}\times\mathbf{B} + \mathbf{E} \right) \Rightarrow$$

$$\begin{cases} m\dfrac{dv_x}{dt} = qv_y B + qE_x \\ m\dfrac{dv_y}{dt} = -qv_x B \\ m\dfrac{dv_z}{dt} = qE_z \end{cases}$$

*Constant acceleration along z*

$$\Rightarrow$$

$$\begin{cases} \dfrac{d^2v_x}{dt^2} = \dfrac{qB}{m}\dfrac{dv_y}{dt} = \omega_g \dfrac{dv_y}{dt} = -\omega_g^2 v_x \\ \dfrac{d^2v_y}{dt^2} = -\dfrac{qB}{m}\dfrac{dv_x}{dt} = -\omega_g \dfrac{dv_x}{dt} = -\omega_g^2 v_y - \dfrac{q^2 B}{m^2} E_x \end{cases}$$

$$\Rightarrow$$

# Drift motion

$$\begin{cases} \dfrac{d^2 v_x}{dt^2} = \dfrac{qB}{m}\dfrac{dv_y}{dt} = \omega_g \dfrac{dv_y}{dt} = -\omega_g^2 v_x \\ \dfrac{d^2 v_y}{dt^2} = -\dfrac{qB}{m}\dfrac{dv_x}{dt} = -\omega_g \dfrac{dv_x}{dt} = -\omega_g^2 v_y - \dfrac{q^2 B}{m^2} E_x \end{cases}$$

$$\therefore$$

$$\begin{cases} \dfrac{d^2 v_x}{dt^2} - \omega_g^2 v_x \\ \dfrac{d^2\left(v_y + \dfrac{E_x}{B}\right)}{dt^2} = -\omega_g^2 \left(v_y + \dfrac{E_x}{B}\right) \end{cases}$$

$\Rightarrow$

$$\begin{cases} v_x = v_\perp e^{i\omega_g t + \delta_x} \\ v_y = -\dfrac{E_x}{B} + v_\perp e^{i\omega_g t + \delta_y} \end{cases}$$

Average over a gyro period:

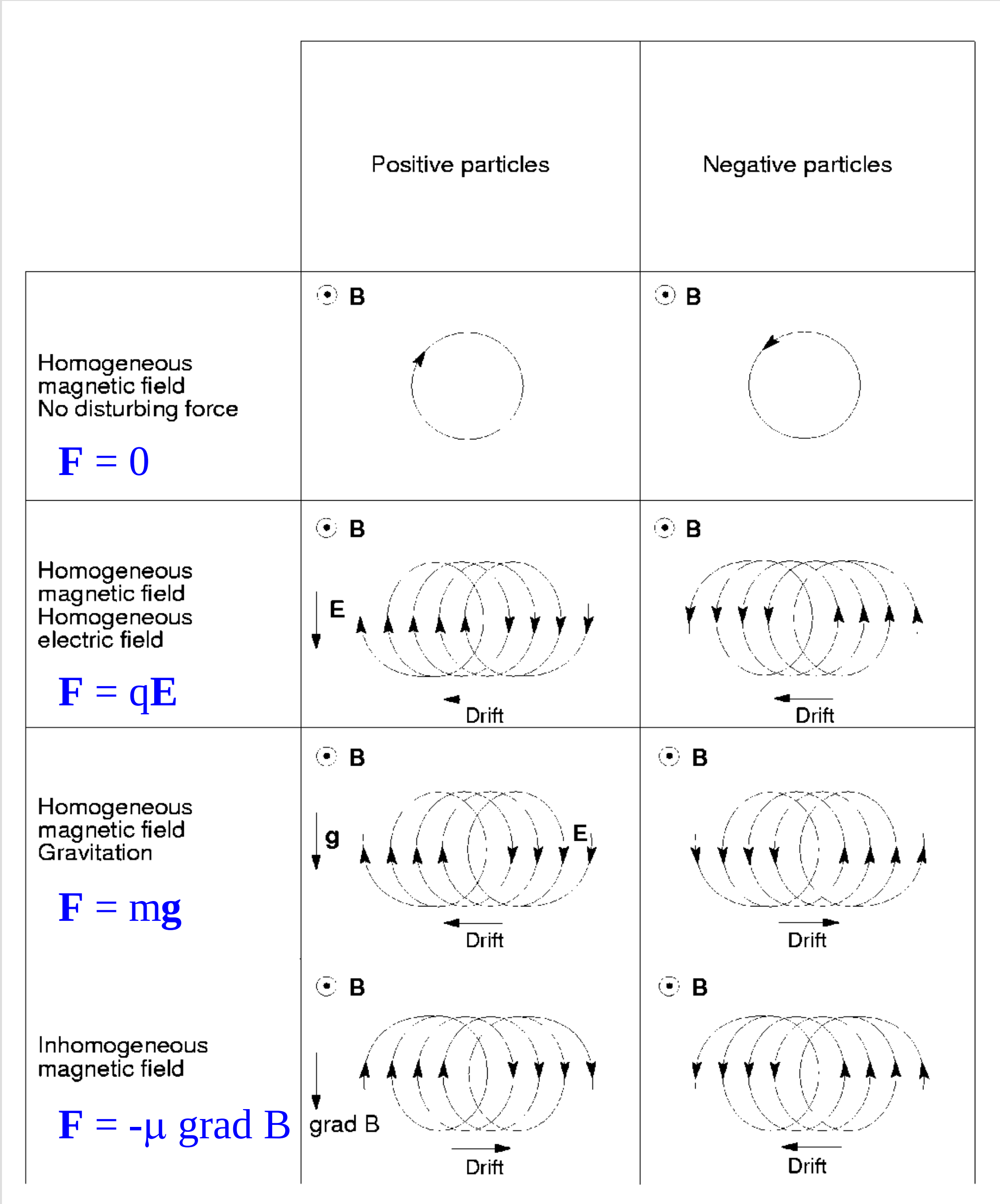
$$v_{drift,y} = -\frac{E_x}{B} = -\frac{E_x B_z}{B^2} = \frac{(\mathbf{E}\times\mathbf{B})_y}{B^2}$$

*In general:*

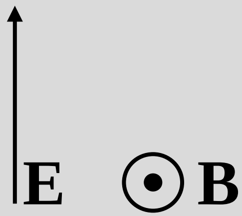
$$\mathbf{v}_{drift} = \frac{\mathbf{E}\times\mathbf{B}}{B^2} = \frac{q\mathbf{E}\times\mathbf{B}}{qB^2} = \frac{\mathbf{F}\times\mathbf{B}}{qB^2}$$

# Drift motion

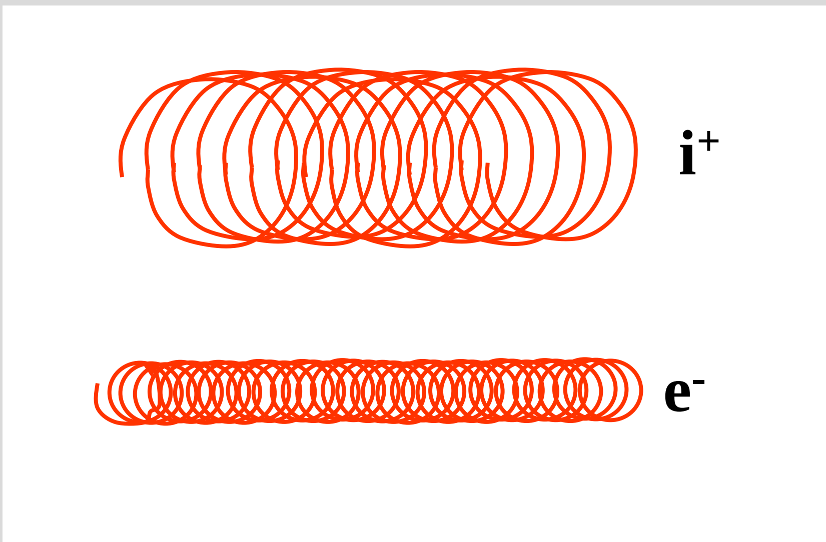
$$\mathbf{u}_{drift} = \frac{\mathbf{F} \times \mathbf{B}}{qB^2}$$



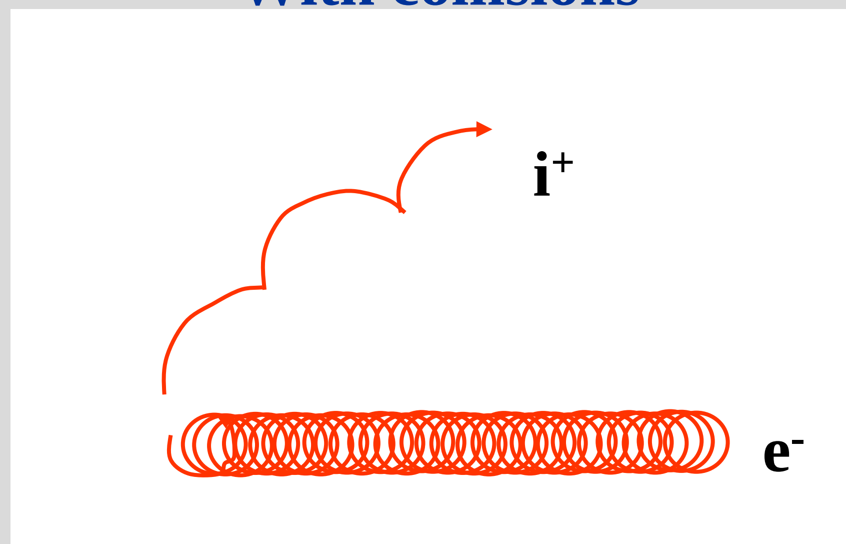
# ExB-drift



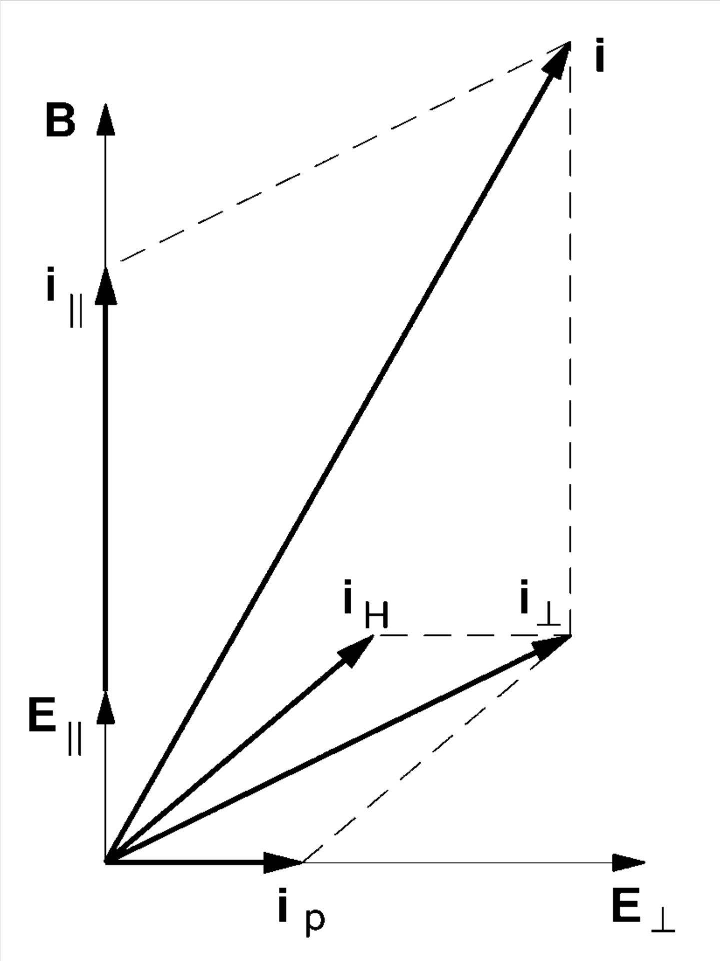

## Without collisions




## With collisions

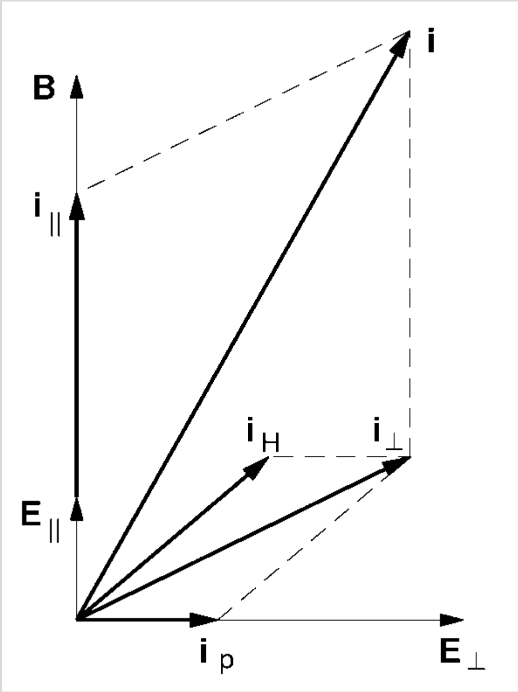


# Electric conductivity in a magnetized plasma




- $i_{//}$ = parallel current
- $i_P$ = Pedersen current
- $i_H$ = Hall current

# Electric conductivity in a magnetized plasma II




$$\sigma_P = \sigma_e \frac{1}{1+\omega_{ge}^2\tau_e^2} + \sigma_i \frac{1}{1+\omega_{gi}^2\tau_i^2}$$

$$\sigma_H = \sigma_e \frac{\omega_{ge}\tau_e}{1+\omega_{ge}^2\tau_e^2} - \sigma_i \frac{\omega_{gi}\tau_i}{1+\omega_{gi}^2\tau_i^2}$$

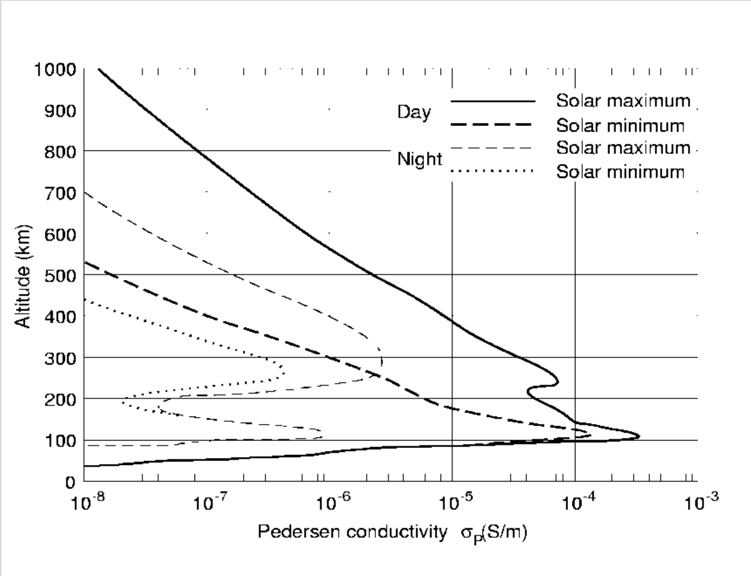
$$\sigma_{//} = \sigma_e + \sigma_i$$

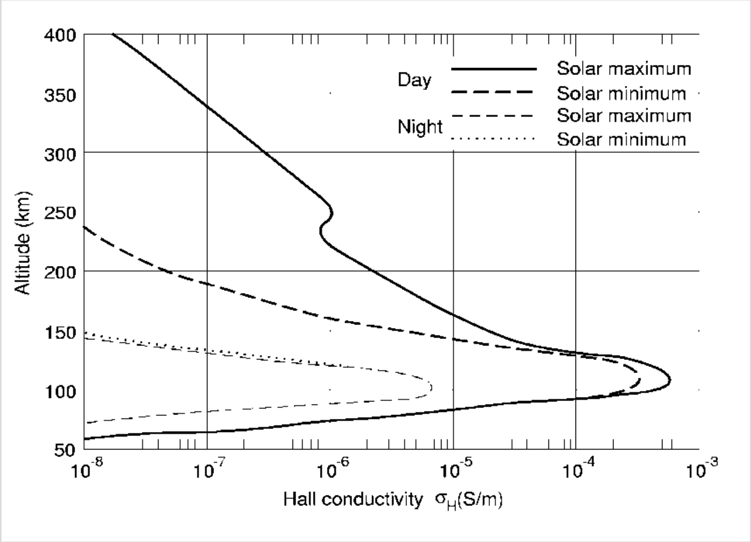
$$\sigma_e = e^2 n \tau_e / m_e \qquad \sigma_i = e^2 n \tau_i / m_i$$

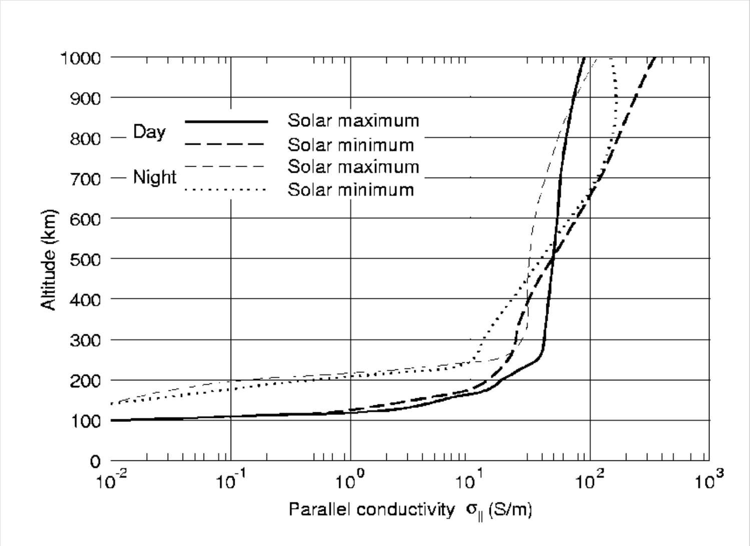
$$i_{//} = \sigma_{//} E_{//}$$

$$\left.\begin{aligned} i_P &= \sigma_P E_\perp \\ i_H &= \sigma_H E_\perp \end{aligned}\right\} \quad \text{or} \quad \mathbf{i}_\perp = \sigma_P \mathbf{E}_\perp + \sigma_H \frac{\mathbf{B}\times\mathbf{E}_\perp}{B}$$

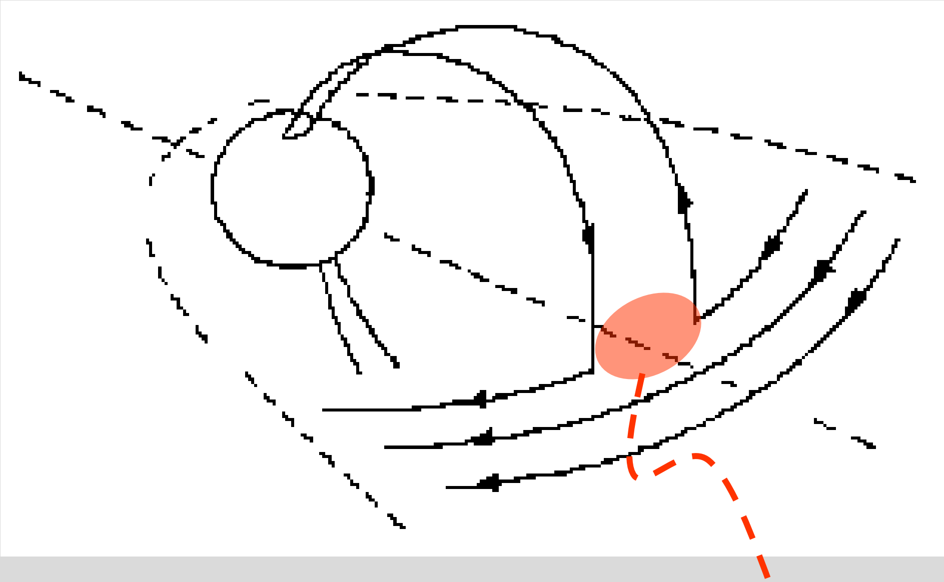
# Ionospheric conductivities



# Consequence: Birkeland currents



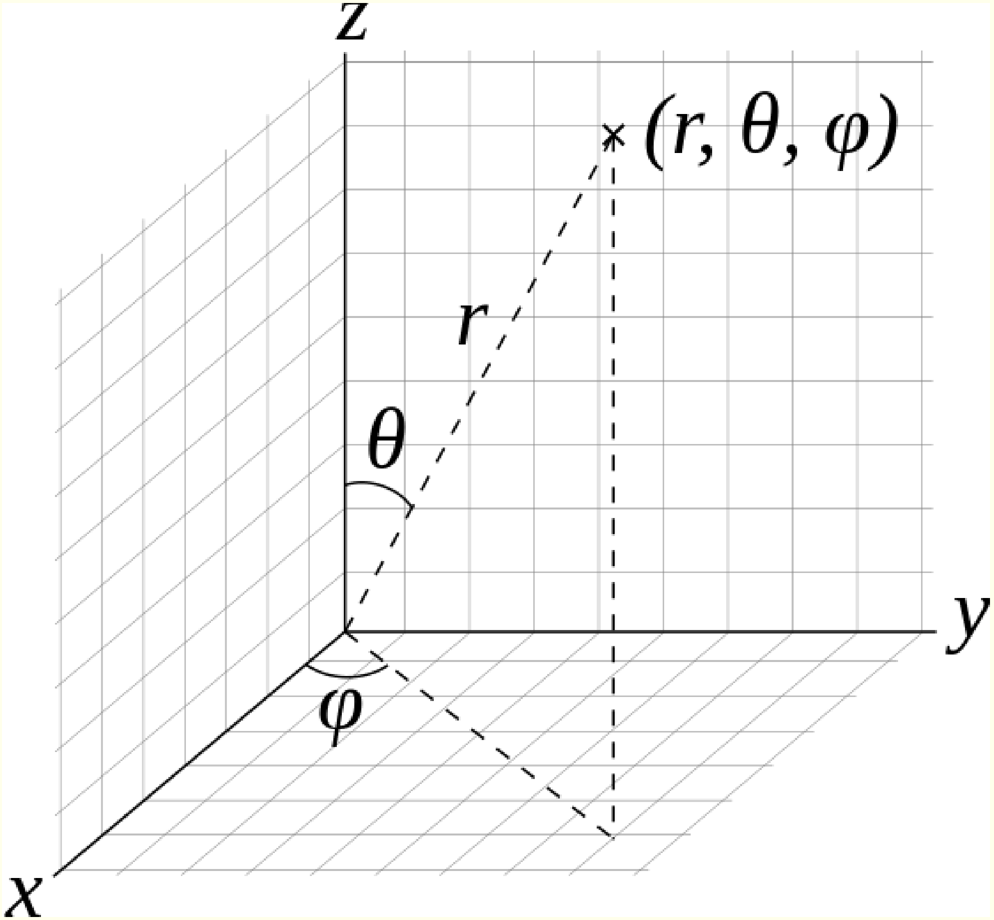
Region of low conductivity

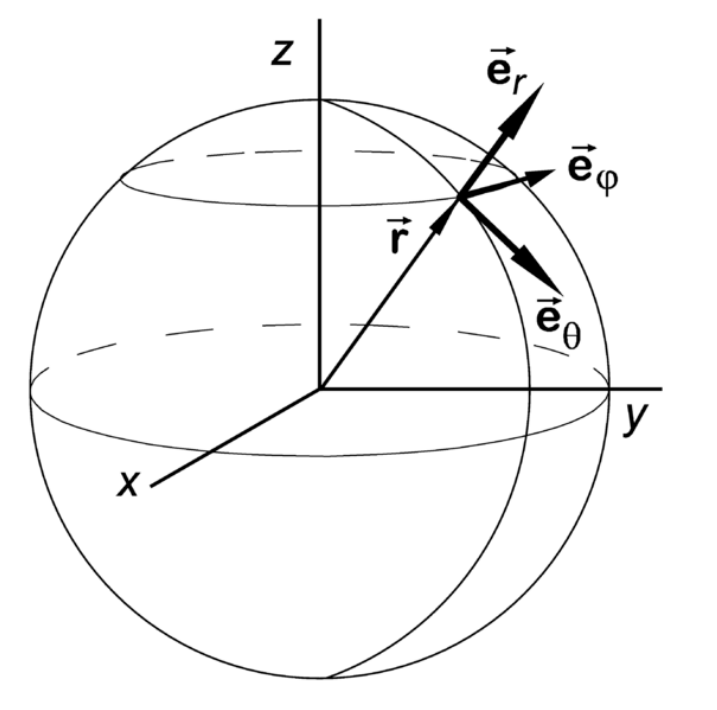
When the conductivity out in the magnetosphere is low, it is easier for the current to close through the ionosphere via currents parallel to the geomagnetic field. Such currents are called *Birkeland* currents.

# How do we define ”the magnetosphere”?

The region in space where the magnetic field is dominated by the geomagnetic field.

# Polar (spherical) coordinates




$$r = \sqrt{x^2 + y^2 + z^2}$$

$$\theta = \arccos\left(\frac{z}{r}\right)$$

$$\varphi = \arctan\left(\frac{y}{x}\right)$$

$$x = r\,\sin\theta\,\cos\varphi$$

$$y = r\,\sin\theta\,\sin\varphi$$

$$z = r\,\cos\theta$$

# Geomagnetic field

Approximated by a dipole close to Earth.

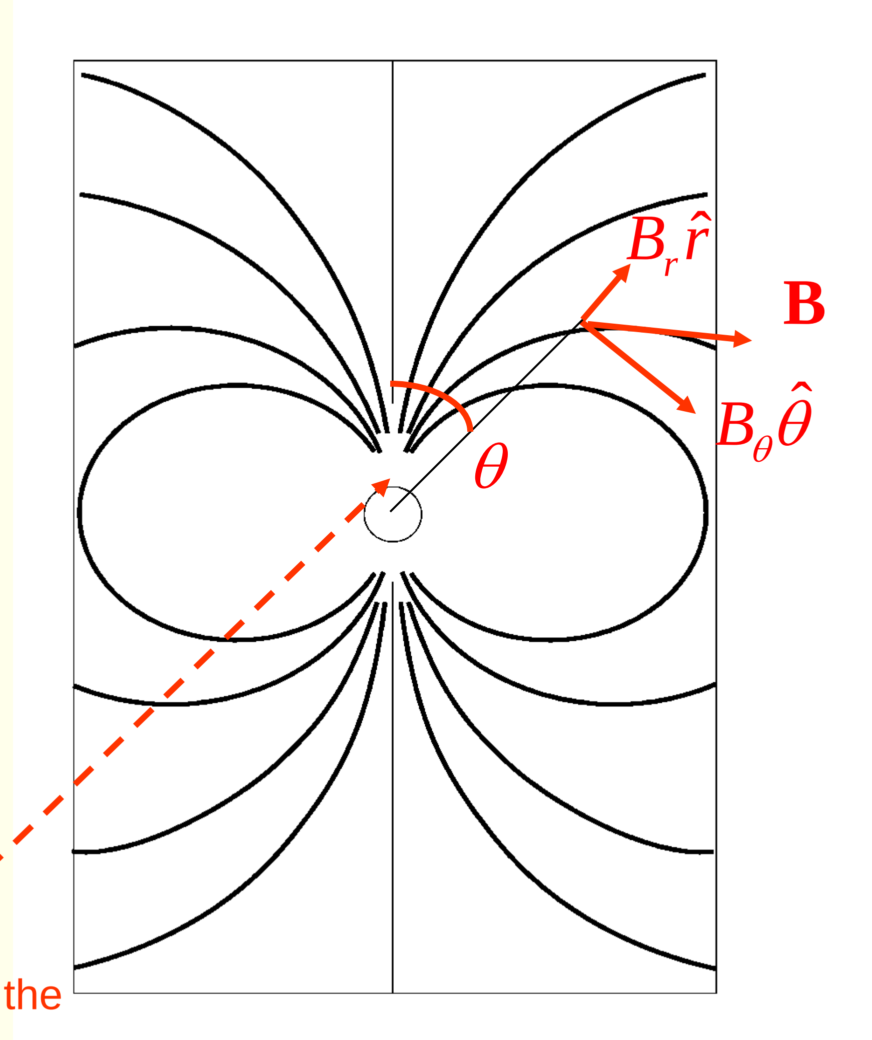
$$B_r = B_p \left(\frac{R_E}{r}\right)^3 \cos\theta$$

$$B_\theta = \frac{B_p}{2} \left(\frac{R_E}{r}\right)^3 \sin\theta$$

$$a = \frac{2\pi R_E^3 B_p}{\mu_0}$$

magnetic dipole moment

Magnetic field at the "north pole"



# Geomagnetic field

Alternative formulation of dipole field

$$B_r = B_p \left(\frac{R_E}{r}\right)^3 \cos\theta \qquad B_r = \frac{\mu_0 a}{2\pi}\frac{1}{r^3}\cos\theta$$

$$B_\theta = \frac{B_p}{2}\left(\frac{R_E}{r}\right)^3 \sin\theta \qquad B_\theta = \frac{\mu_0 a}{2\pi}\cdot\frac{1}{2}\cdot\frac{1}{r^3}\sin\theta$$

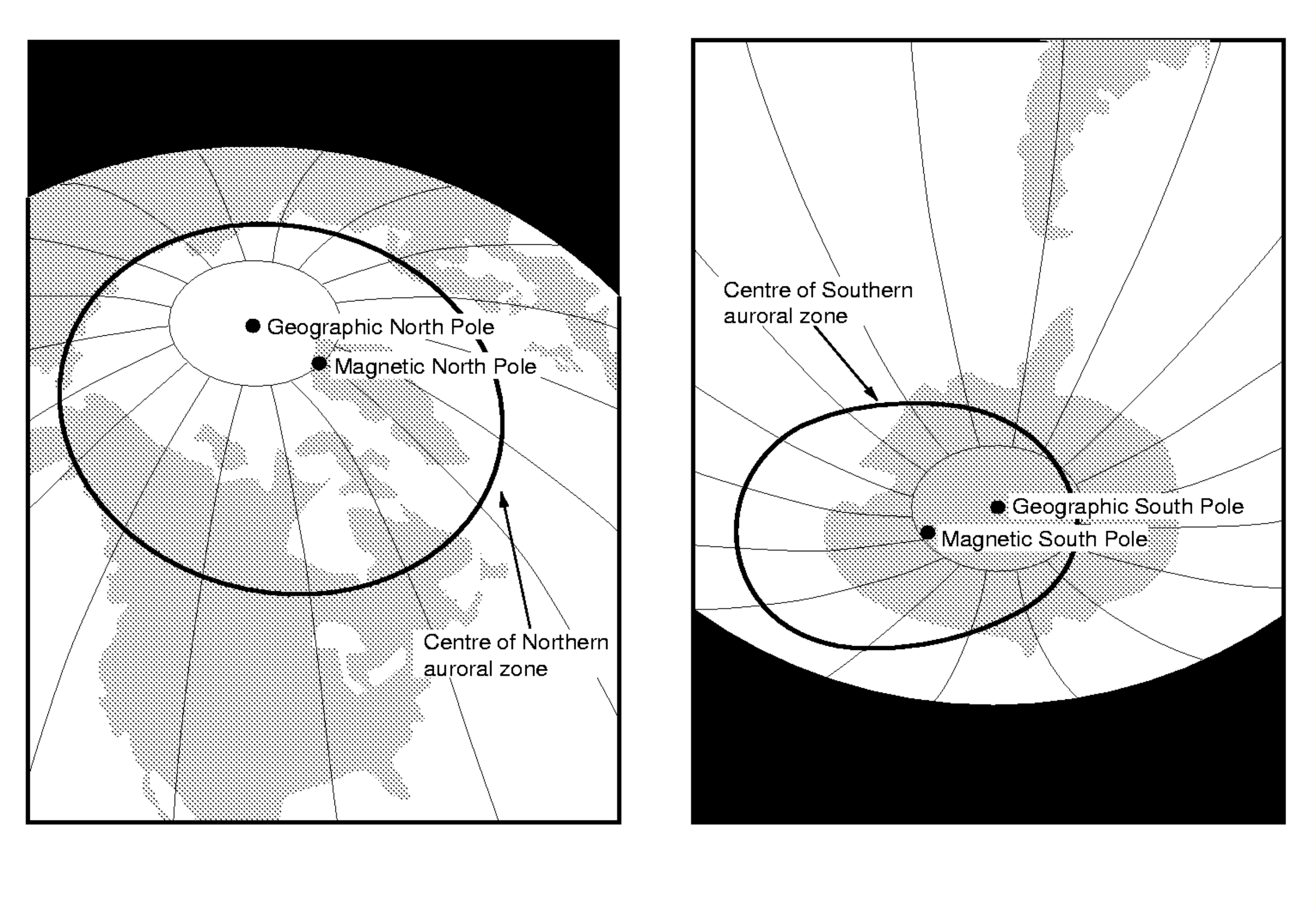
$$a = \frac{2\pi R_E^3 B_p}{\mu_0}$$

magnetic dipole moment

# Geomagnetic field

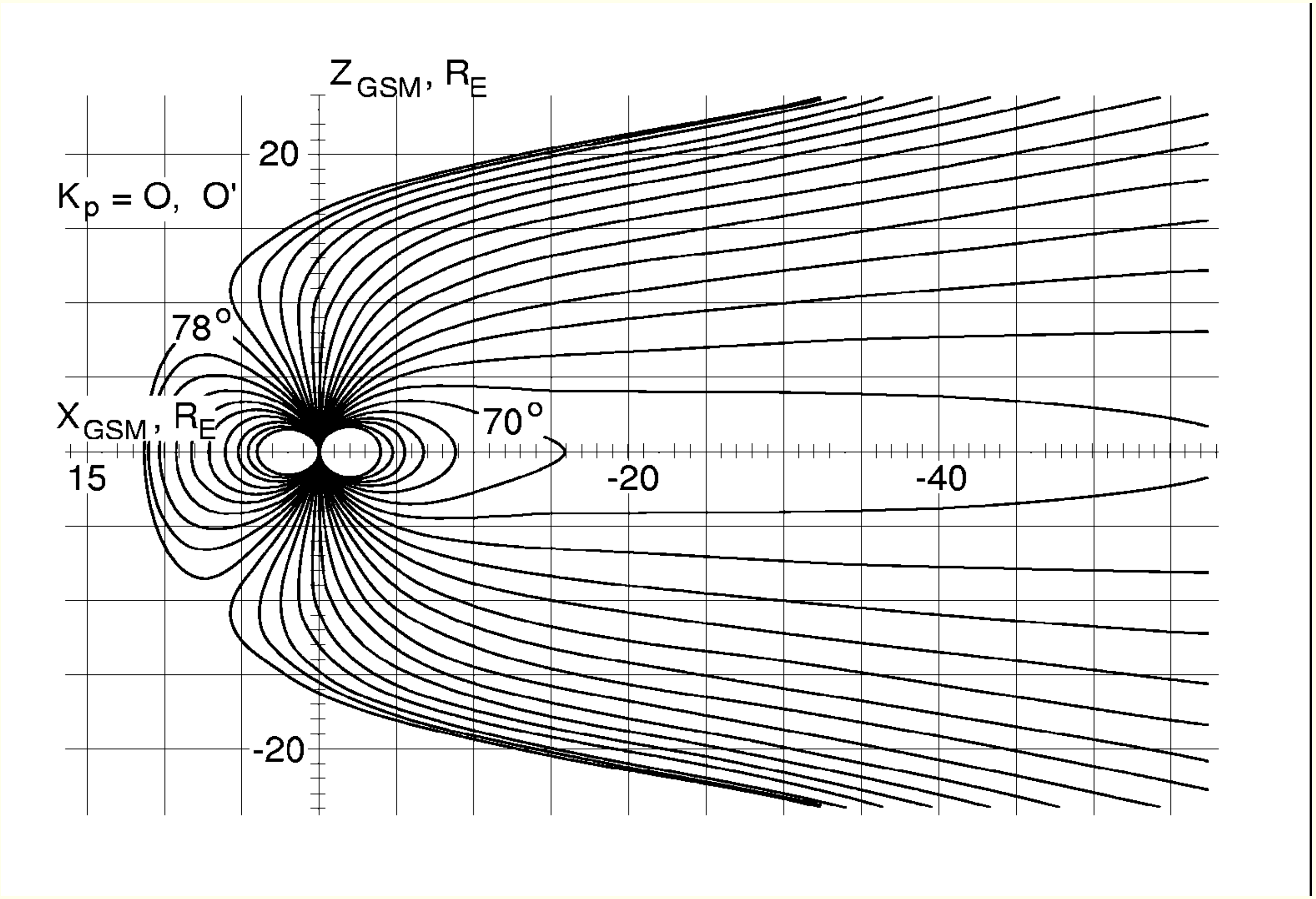
- Angle between dipole axis and spin axis: ≈ 11°
- The geographic north pole is a magnetic south pole, and vice versa.
- $B_{equator} = 31\ \mu T$,

  $B_{pole} = 62\ \mu T$



# Geomagnetic field

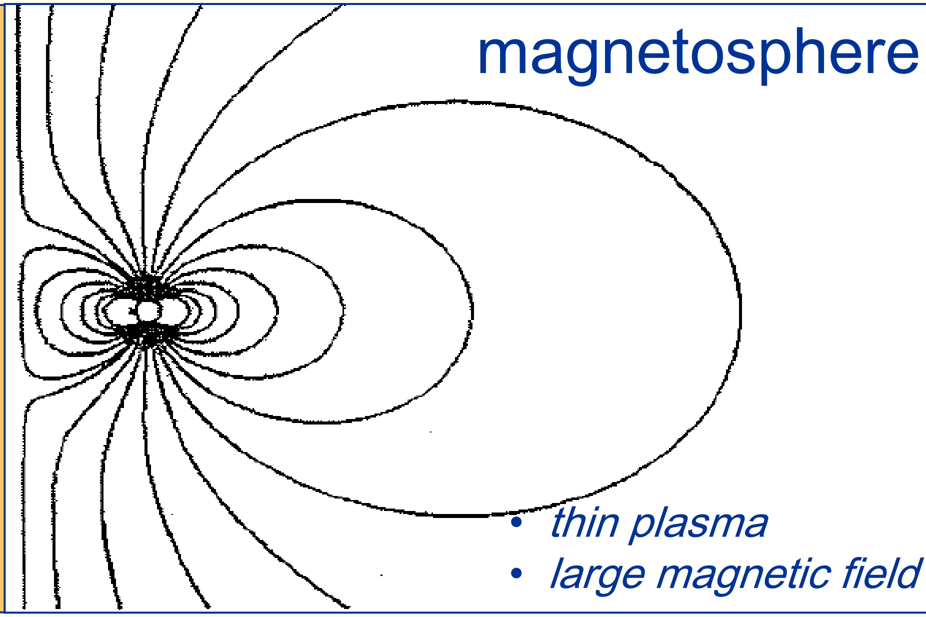
Modified by solar wind into tail-like configuration



# Stand-off distance from pressure balance

solar wind

- *dense plasma with* ***high conductivity***
- *weak magnetic field*



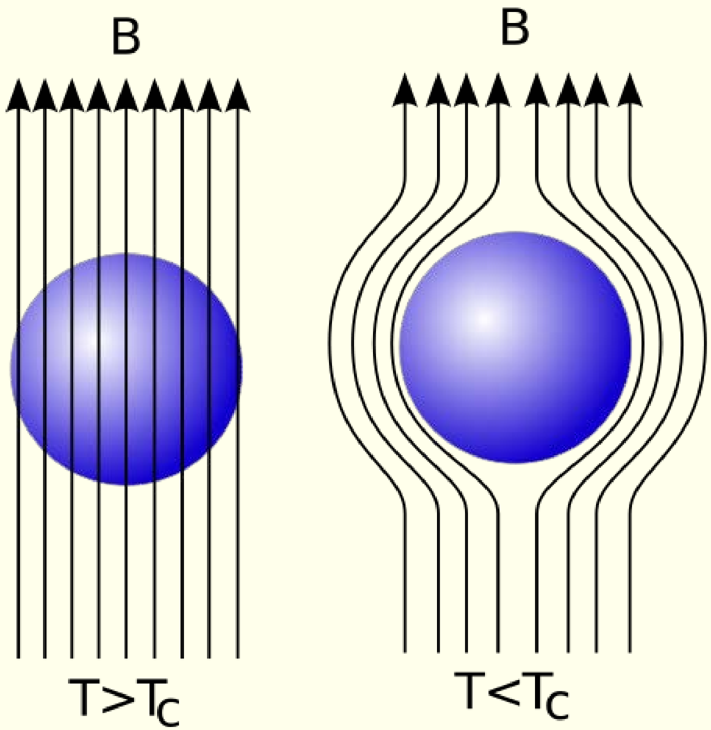

Dynamic pressure:

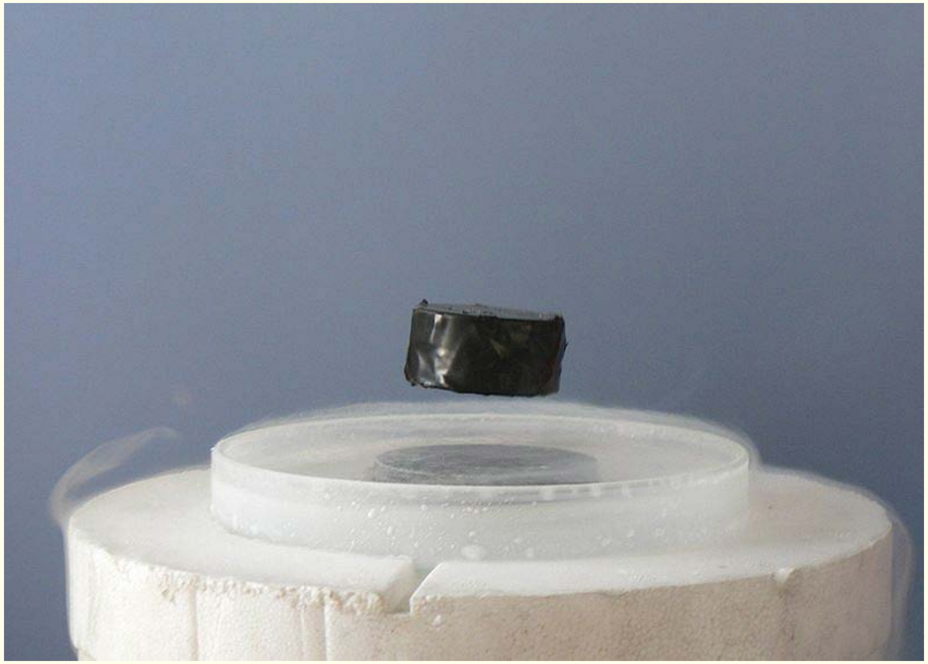
$$p_d = \rho_{SW} v_{SW}^2$$

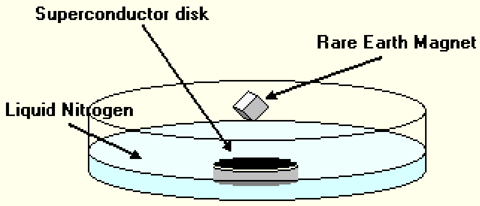
Magnetic pressure:

$$p_B = \frac{B^2}{2\mu_0}$$

# Meissner effect in super-conductors

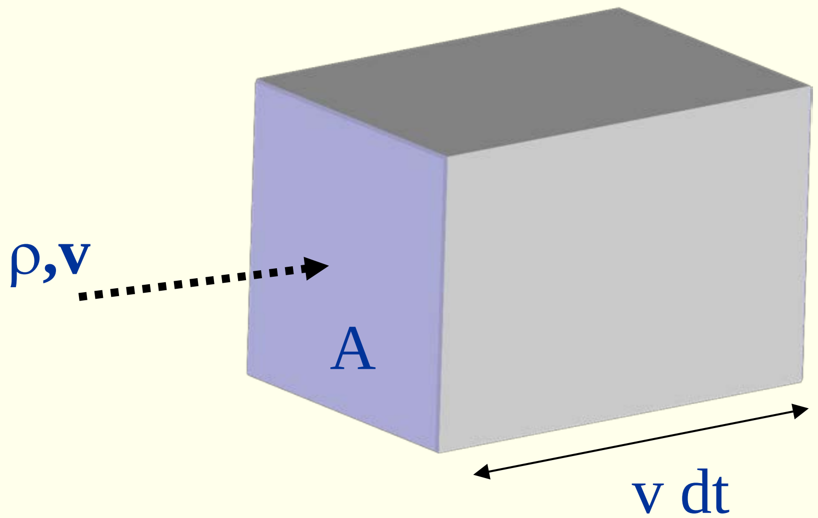




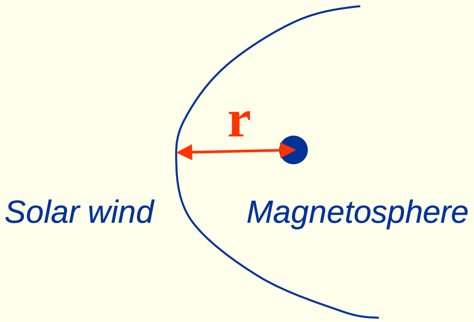

The Meissner Effect

# Dynamic (kinetic) pressure




$$p_d = \frac{F}{A} = \frac{d(mv)}{dt}\frac{1}{A} \approx \frac{\Delta(mv)}{\Delta t}\frac{1}{A} = \frac{\rho \cdot Av\Delta t \cdot v}{\Delta t A} = \rho v^2$$

# Magnetopause "stand-off distance"




Dynamic pressure: $$p_d = \rho_{SW} v_{SW}^2$$

Magnetic pressure: $$p_B = \frac{1}{2\mu_0} B^2$$

Dipole field strength (in equatorial plane): $$B = \frac{\mu_0 a}{4\pi} \frac{1}{r^3}$$

$$p_d = p_B \quad \Rightarrow \quad \rho_{SW} v_{SW}^2 = \left[ \frac{\mu_0 a}{4\pi} \frac{1}{r^3} \right]^2 / 2\mu_0 \quad \Rightarrow$$

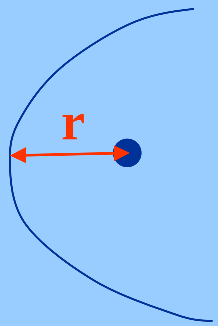
$$r = \left( \frac{\mu_0 a}{4\pi} \right)^{1/3} \left( 2\mu_0 \rho_{SW} v_{SW}^2 \right)^{-1/6}$$

a = $8 \times 10^{22}$ Am$^2$, v=500 km/s, $\rho_{SW} = 10^7 \times 1.7 \times 10^{-27}$ kg/m$^3$:

**r = 7 $R_e$** (1 $R_e$ = 6378 km)

# Standoff distance

v=500 km/s, $\rho_{SW}=10^7 \times 1.7 \times 10^{-27}$ kg/m$^3$: **r = 7 R$_e$**




$$r = \left(\frac{\mu_0 a}{4\pi}\right)^{1/3} \left(2\mu_0 \rho_{SW} v_{SW}^2\right)^{-1/6}$$

How will the standoff distance change if the magnetosphere is hit by a coronal mass ejection (CME)? ($\rho = 10\rho_{SW}$, $v = 1000$ km/s)

| | |
|---|---|
| Blue | r = 1.8 R$_e$ |
| Green | r = 3.8 R$_e$ |
| Yellow | r = 5.8 R$_e$ |
| Red | r = 9.8 R$_e$ |

# Standoff distance

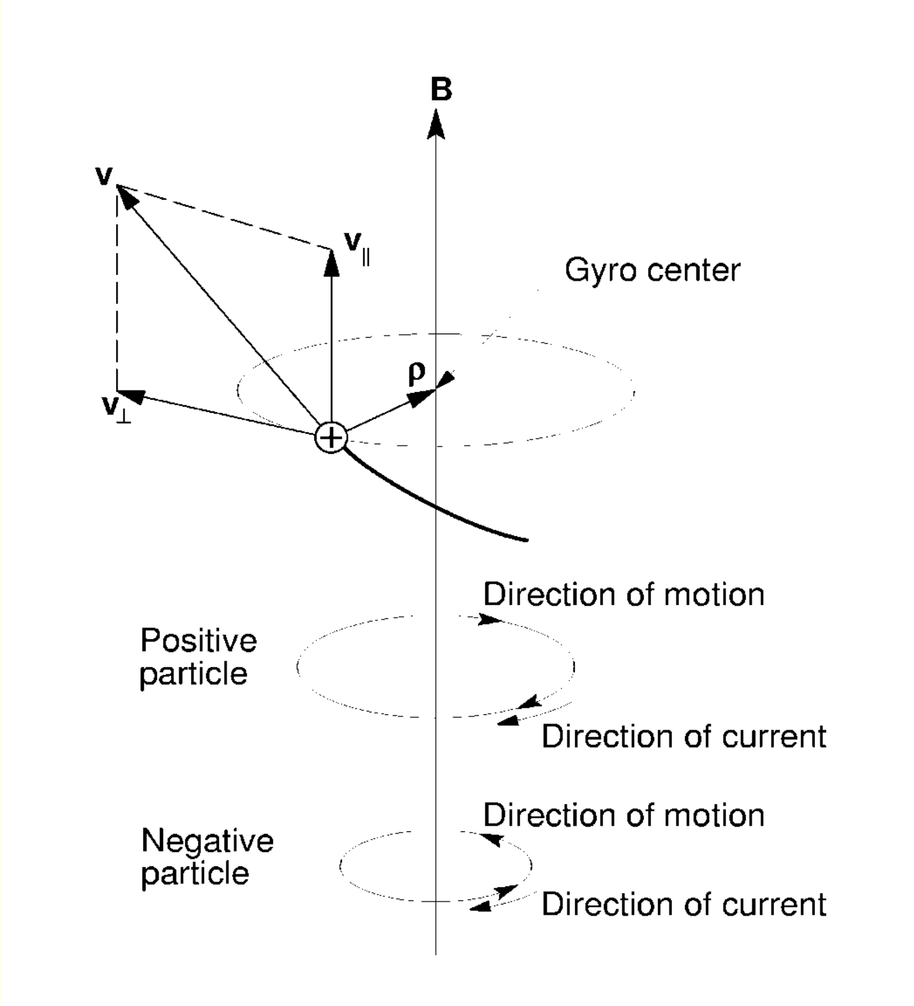
$$r = \left(\frac{\mu_0 a}{4\pi}\right)^{1/3} \left(2\mu_0 10 \rho_{SW} (2v)_{SW}^2\right)^{-1/6} = \left(\frac{\mu_0 a}{4\pi}\right)^{1/3} \left(2\mu_0 \rho_{SW} v_{SW}^2\right)^{-1/6} 40^{-1/6}$$

$40^{-1/6} \cdot 7 = 0.54 \cdot 7 = 3.8$

Green

$r = 3.8\ R_e$

# Particle motion in magnetic field




## gyro radius

$$\rho = \frac{mv_\perp}{qB}$$

## gyro frequency

$$\omega_g = \frac{qB}{m}$$

## magnetic moment

$$\mu = IA = q\, f_g \pi\, \rho^2 = mv_\perp{}^2/2B$$

# Adiabatic invariant

**DEFINITION:**

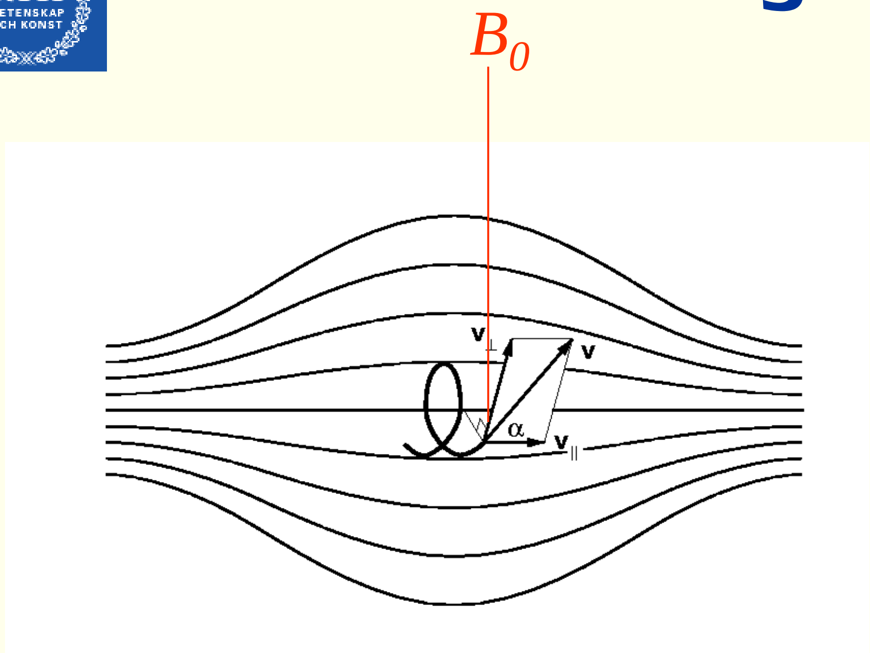
An **adiabatic invariant** is a property of a physical system which stays constant when changes are made slowly.

*By ’slowly’ in the context of charged particle motion in magnetic fields, we mean much slower than the gyroperiod.*

’First adiabatic invariant’ of particle drift:

$$\mu = \frac{mv_\perp^2}{2B}$$

# Magnetic mirror




$mv^2/2$ constant (energy conservation)

$$\frac{\sin^2\alpha}{B} = konst$$

What happens with $\alpha$ as the particle moves into the stronger magnetic field?

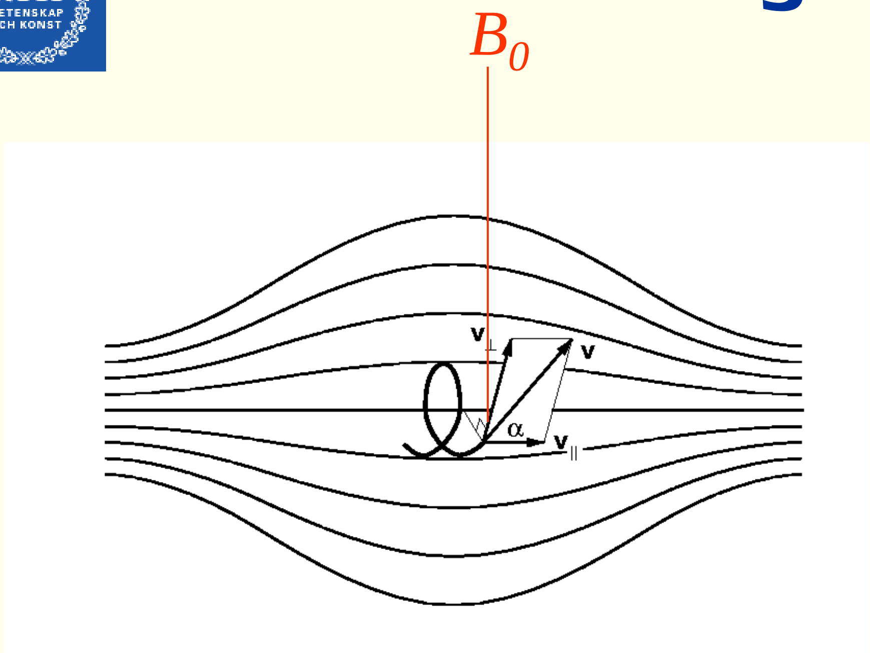
Red — $\alpha$ increases

Yellow — $\alpha$ decreases

The magnetic moment $\mu$ is an ***adiabatic invariant***.

$$\mu = \frac{mv_\perp^2}{2B} = \frac{mv^2\sin^2\alpha}{2B}$$

# Magnetic mirror




$mv^2/2$ constant (energy conservation) ➡

$$\frac{\sin^2\alpha}{B} = konst$$

The magnetic moment $\mu$ is an ***adiabatic invariant***.

$$\mu = \frac{mv_\perp^2}{2B} = \frac{mv^2\sin^2\alpha}{2B}$$

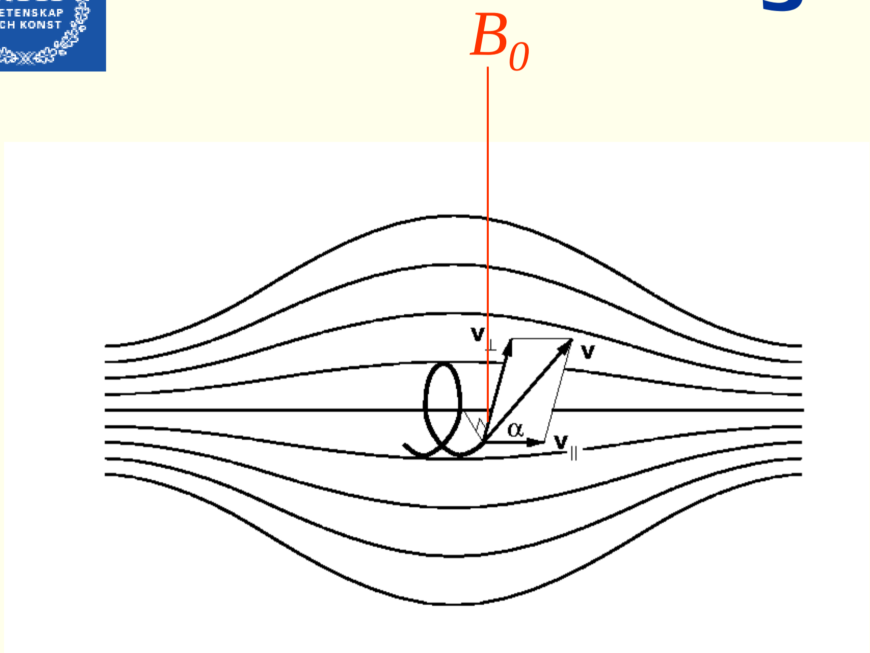
What happens with $\alpha$ as the particle moves into the stronger magnetic field?

$$\sin\alpha = \sqrt{B\cdot konst}$$

Red

$\alpha$ increases

# Magnetic mirror




$mv^2/2$ constant (energy conservation)

$$\frac{\sin^2\alpha}{B} = konst$$

particle turns when α = 90°

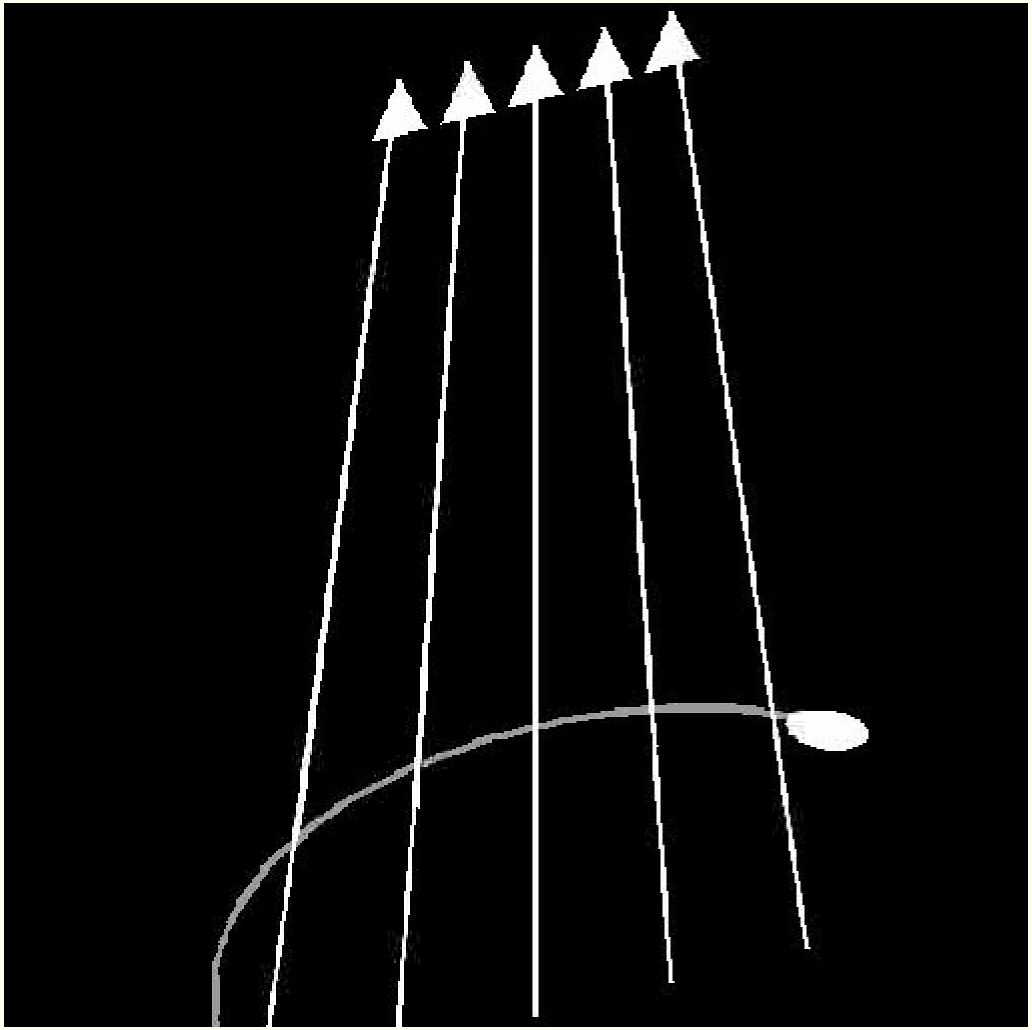
$$\frac{B_{turn}}{\sin^2 90^\circ} = \frac{B_0}{\sin^2\alpha}$$

$$B_{turn} = \frac{B_0}{\sin^2\alpha}$$

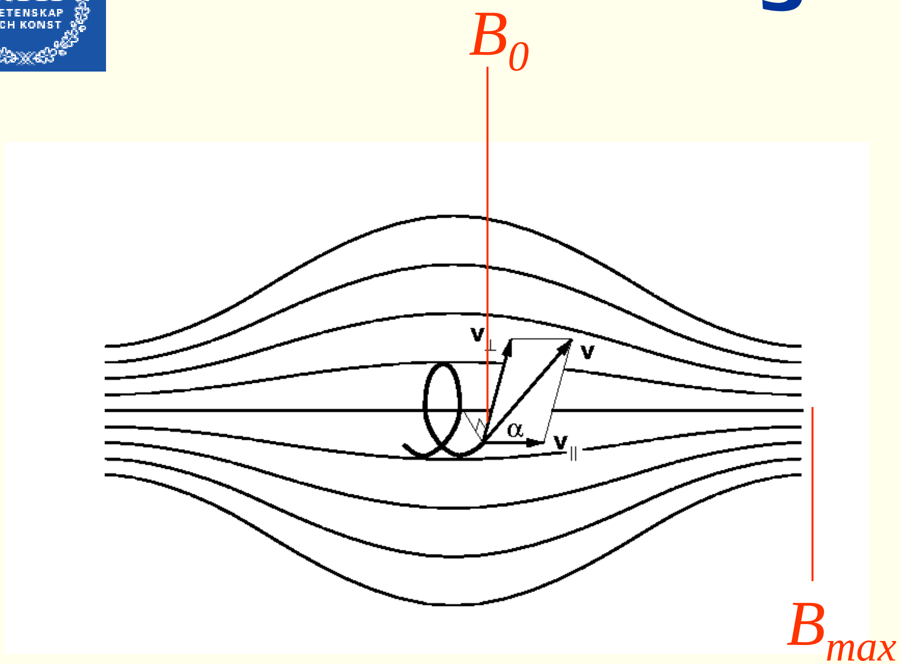
The magnetic moment $\mu$ is an ***adiabatic invariant***.

$$\mu = \frac{mv_\perp^2}{2B} = \frac{mv^2\sin^2\alpha}{2B}$$

# Magnetic mirror



# Magnetic mirror




$mv^2/2$ constant (energy conservation) ➡

$$\frac{\sin^2 \alpha}{B} = konst$$

particle turns when α = 90° ➡

$$B_{turn} = B_0 / \sin^2 \alpha$$

If maximal *B*-field is $B_{max}$ a particle with pitch angle $\alpha$ can only be turned around if

$$B_{turn} = B_0 / \sin^2 \alpha \le B_{\max}$$ ➡

$$\alpha > \alpha_{lc} = \arcsin \sqrt{B_0 / B_{\max}}$$

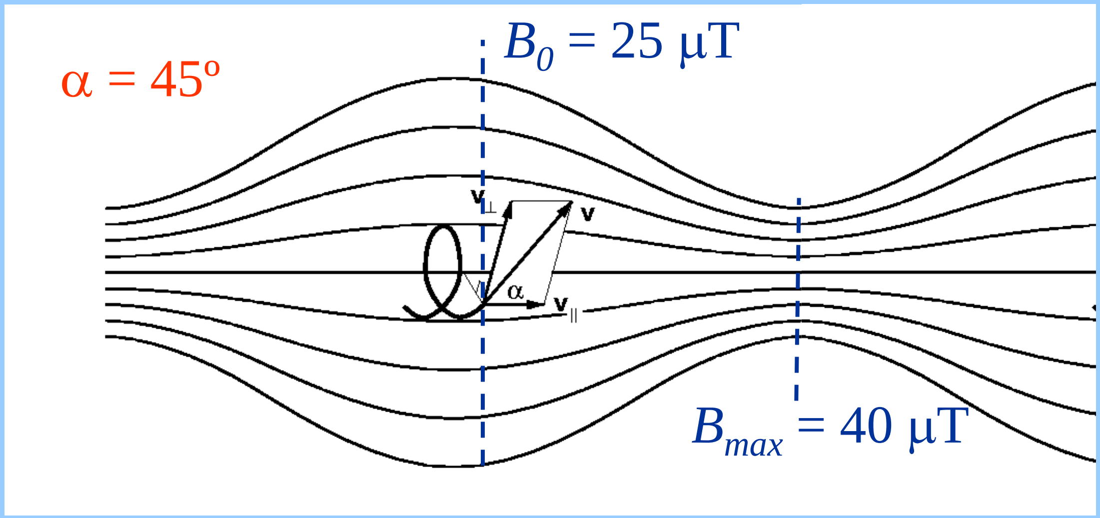
Particles in ***loss cone*** :

$$\alpha < \alpha_{lc}$$

The magnetic moment $\mu$ is an ***adiabatic invariant***.

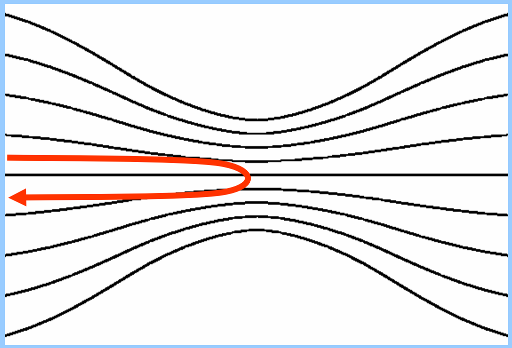
$$\mu = \frac{mv_\perp^2}{2B} = \frac{mv^2 \sin^2 \alpha}{2B}$$

# What will happen to the particle?

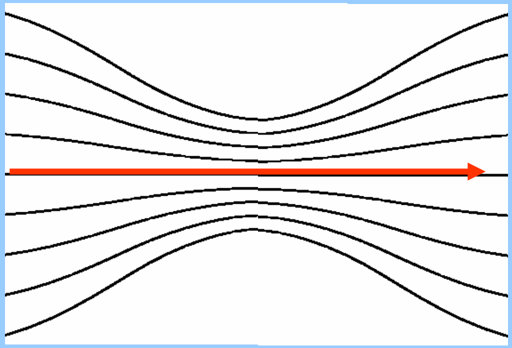



$$\alpha_{lc} = \arcsin \sqrt{B_0 / B_{max}}$$

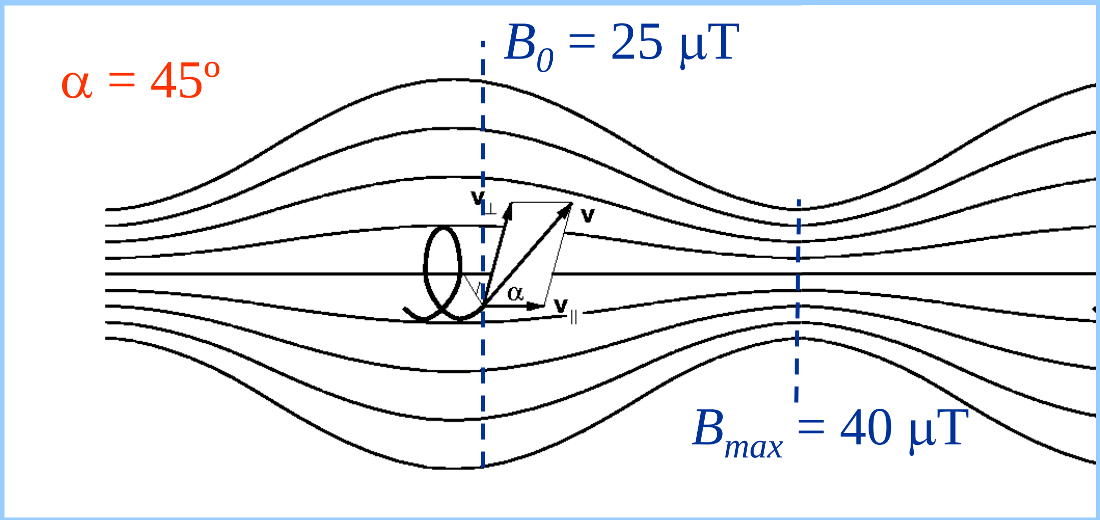
Blue It will mirror



Yellow It will escape

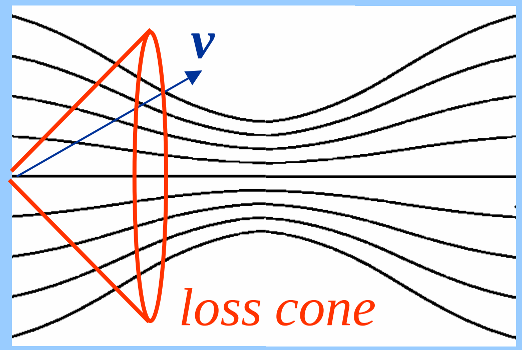


# What will happen to the particle?



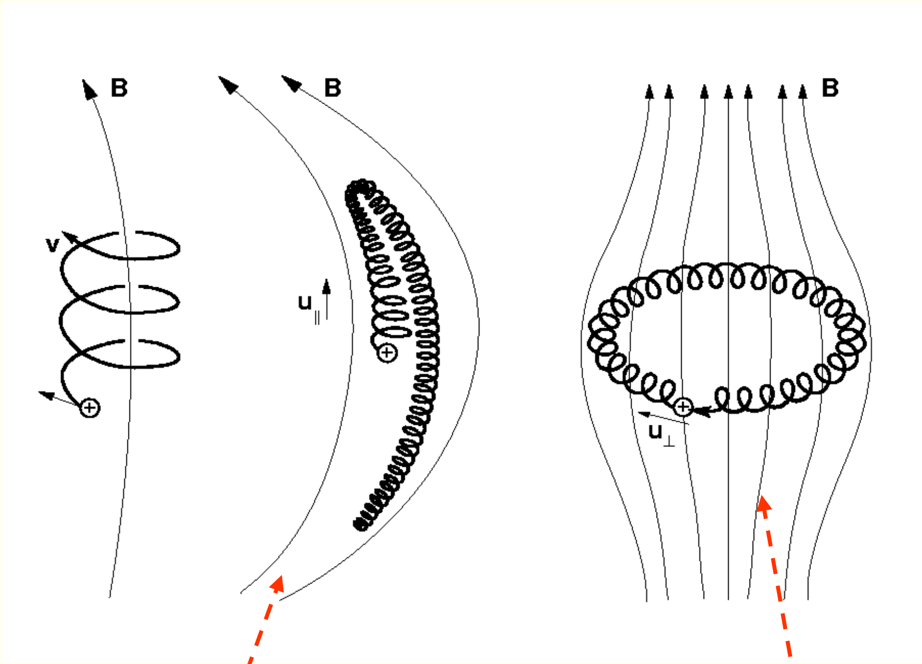

$$\alpha_{lc} = \arcsin\sqrt{B_0 / B_{\max}} = \arcsin\sqrt{25/40} = 52°$$

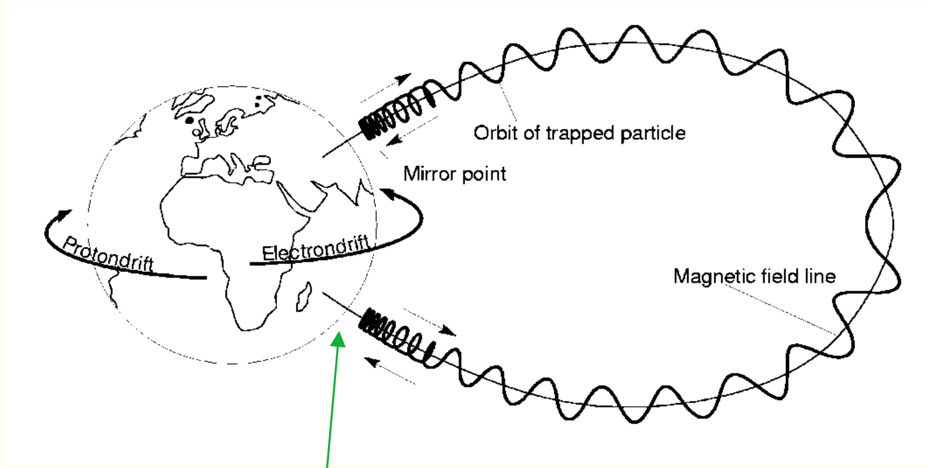
Yellow It will escape



# Particle motion in geomagnetic field

**gyration** **longitudinal oscillation** **azimuthal drift**



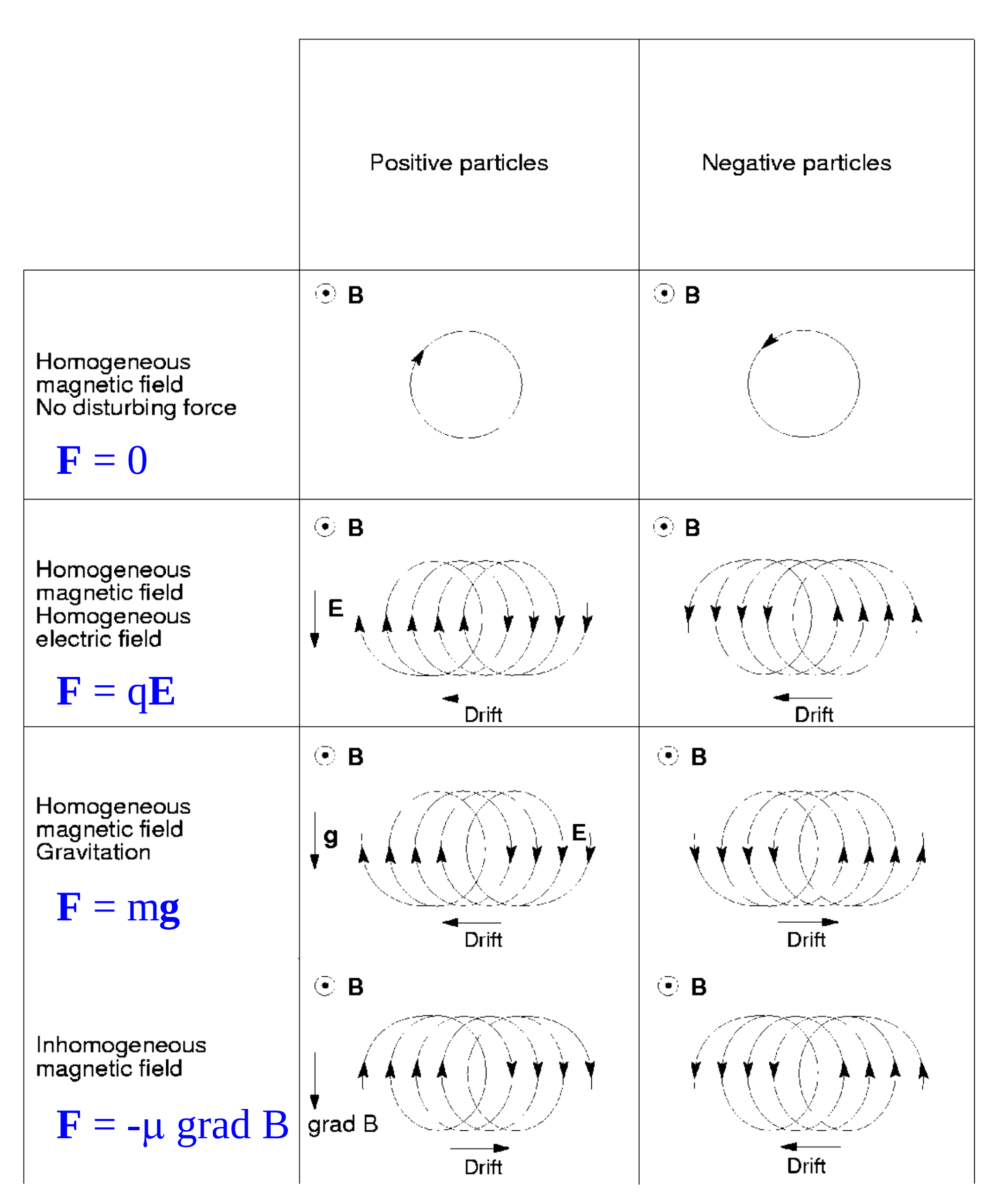

Magnetic mirror

grad B drift

Particles in the loss cone create the aurora!

# Drift motion

$$\mathbf{u} = \frac{\mathbf{F} \times \mathbf{B}}{qB^2}$$

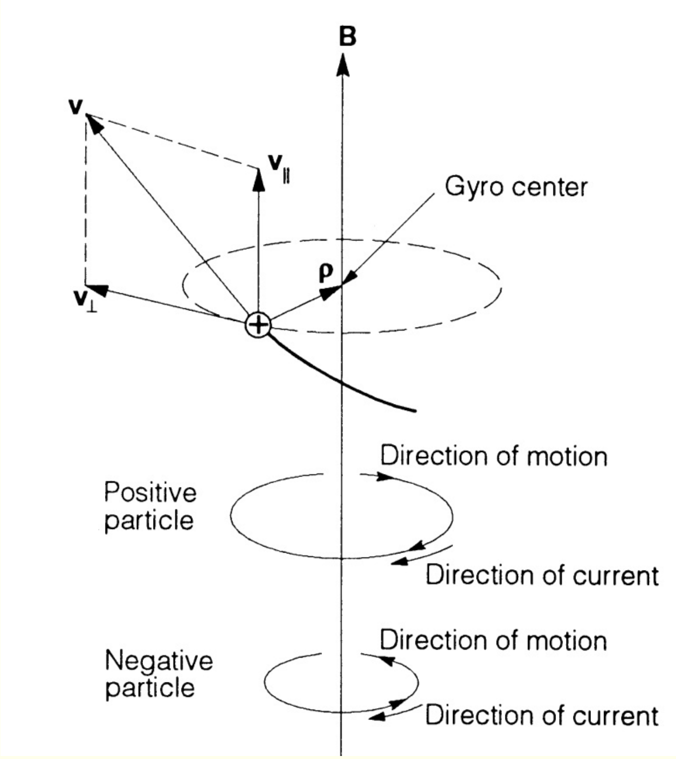


# Force on magnetic dipole

$$\boldsymbol{\mu} \sim -\mathbf{B} \quad \Rightarrow \quad \boldsymbol{\mu} = -\mu \frac{\mathbf{B}}{B}$$

$$\mathbf{F} = \nabla(\boldsymbol{\mu} \cdot \mathbf{B}) = -\mu \nabla \left( \frac{\mathbf{B}}{B} \cdot \mathbf{B} \right) =$$

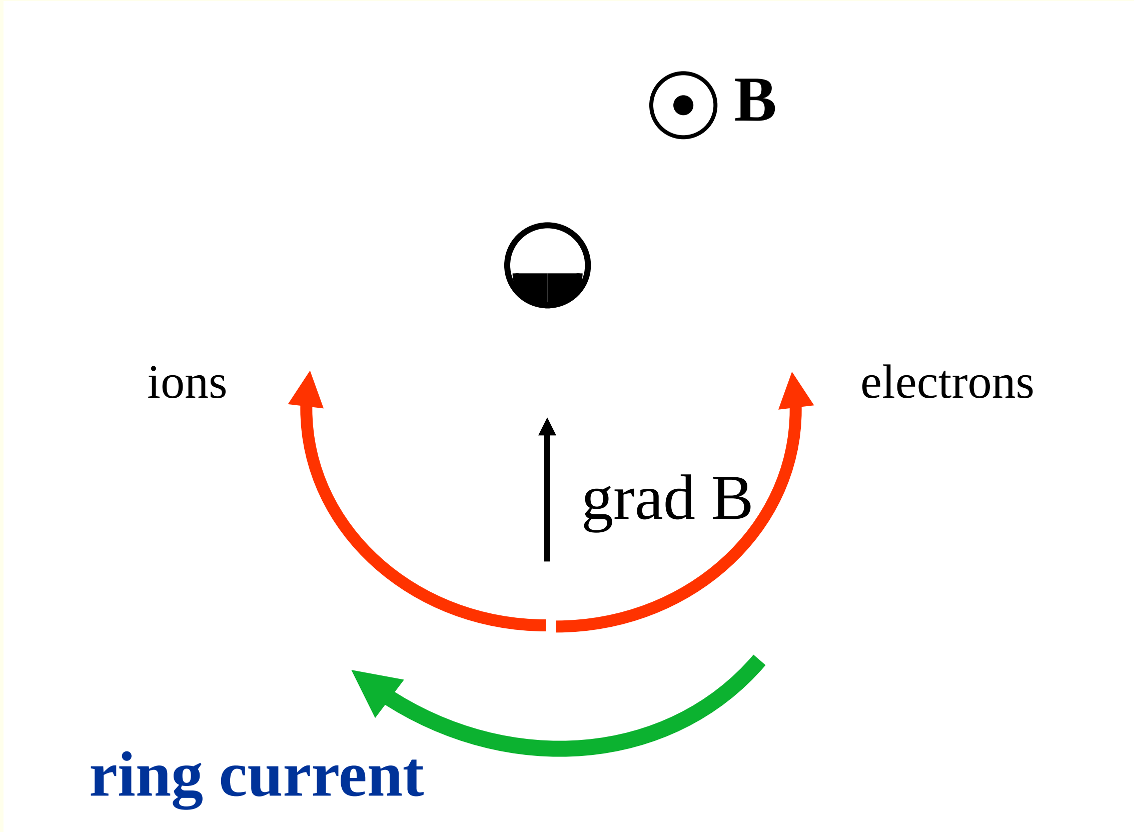
$$= -\mu \nabla \left( \frac{B^2}{B} \right) = -\mu \nabla B$$



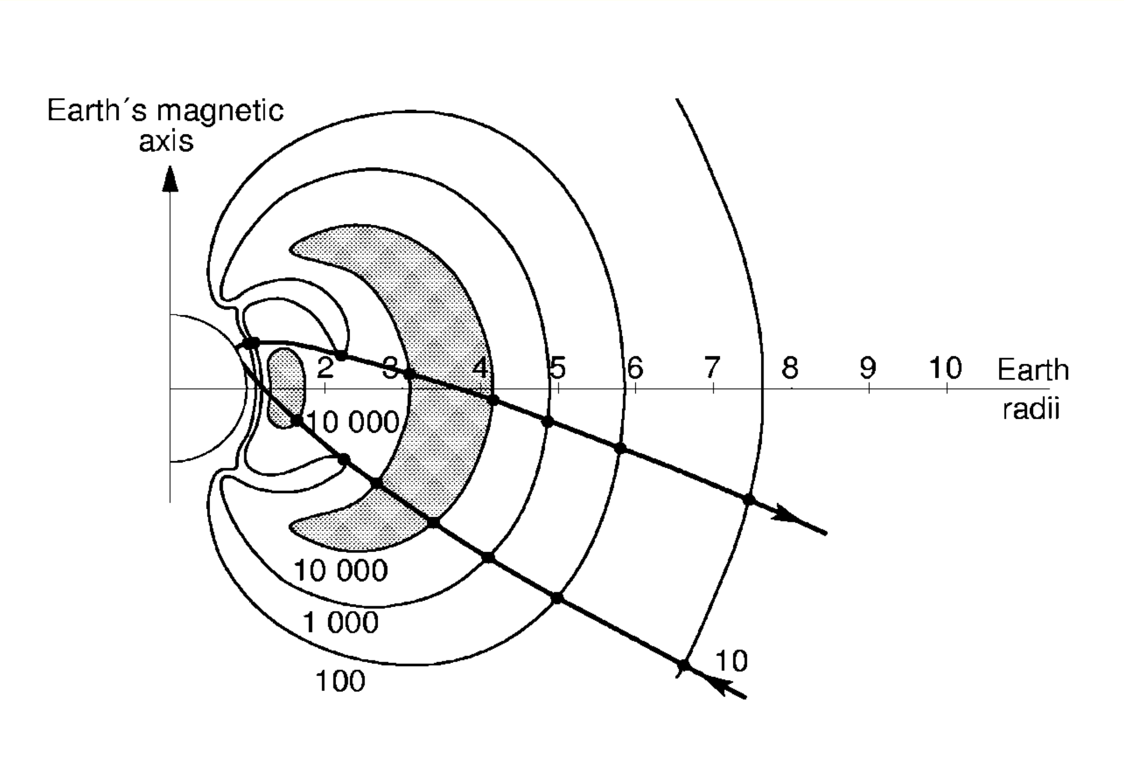
# Ring current and particle motion

$$\mathbf{u} = -\frac{\mu \nabla B \times \mathbf{B}}{qB^2}$$

$$\mu = \frac{m v_\perp^2}{2B}$$



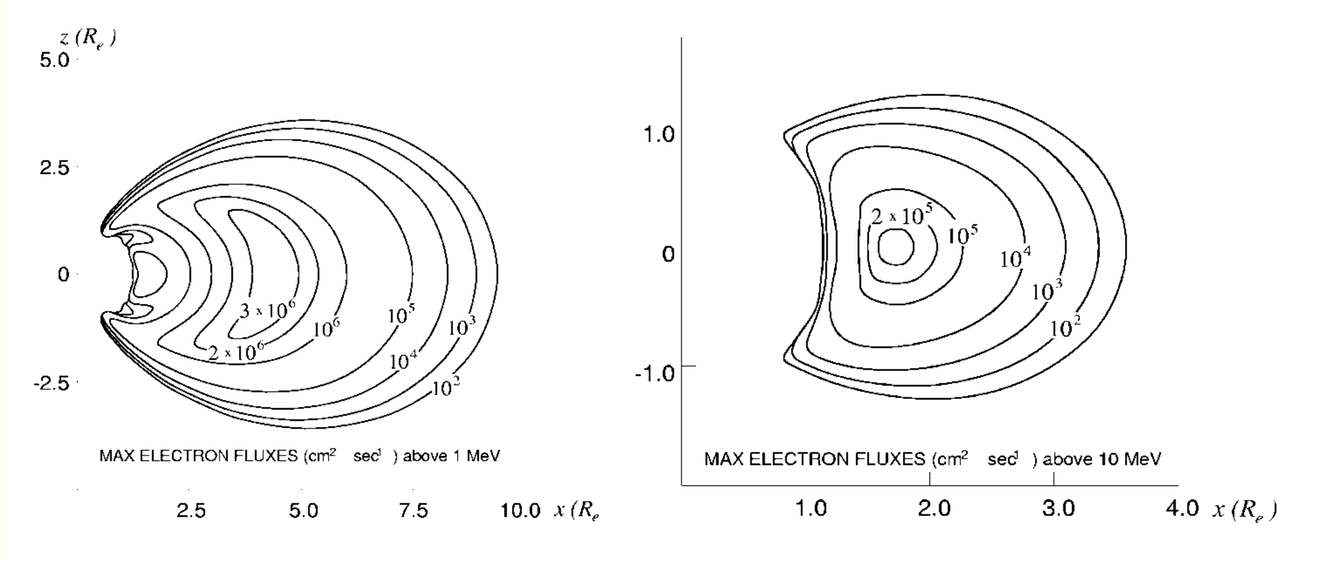
# Radiation belts




## I. Van Allen belts

- Discovered in the 50s , Explorer 1
- Inner belt contains protons with energies of ~30 MeV
- Outer belt (Explorer IV, Pioneer III): electrons, *W* >1.5 MeV

# Radiation belts




- At lower energies there is a more or less continous population of energetic particles in the inner magnetosphere. (Inner part of ***plasma sheet***)

- source: **CRAND** (Cosmic Ray Albedo Neutron Decay).
- a danger for satellites and astronauts.
- associated with a current (***ring current***) which distorts the inner part of the geomagnetic field.

# CRAND (Cosmic Ray Albedo Neutron Decay

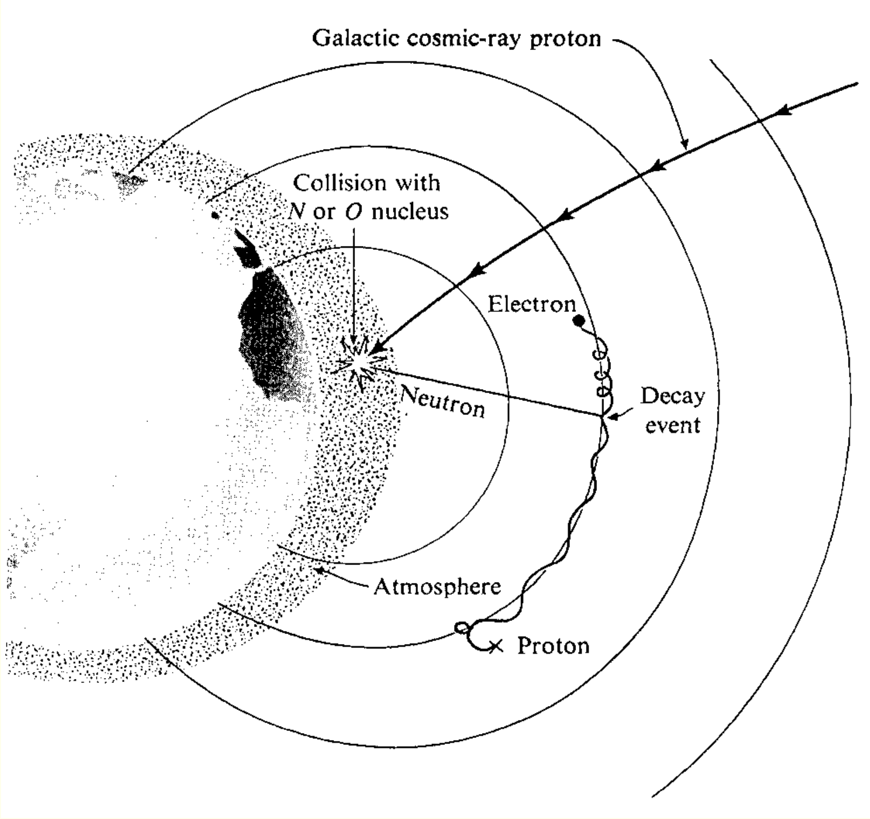
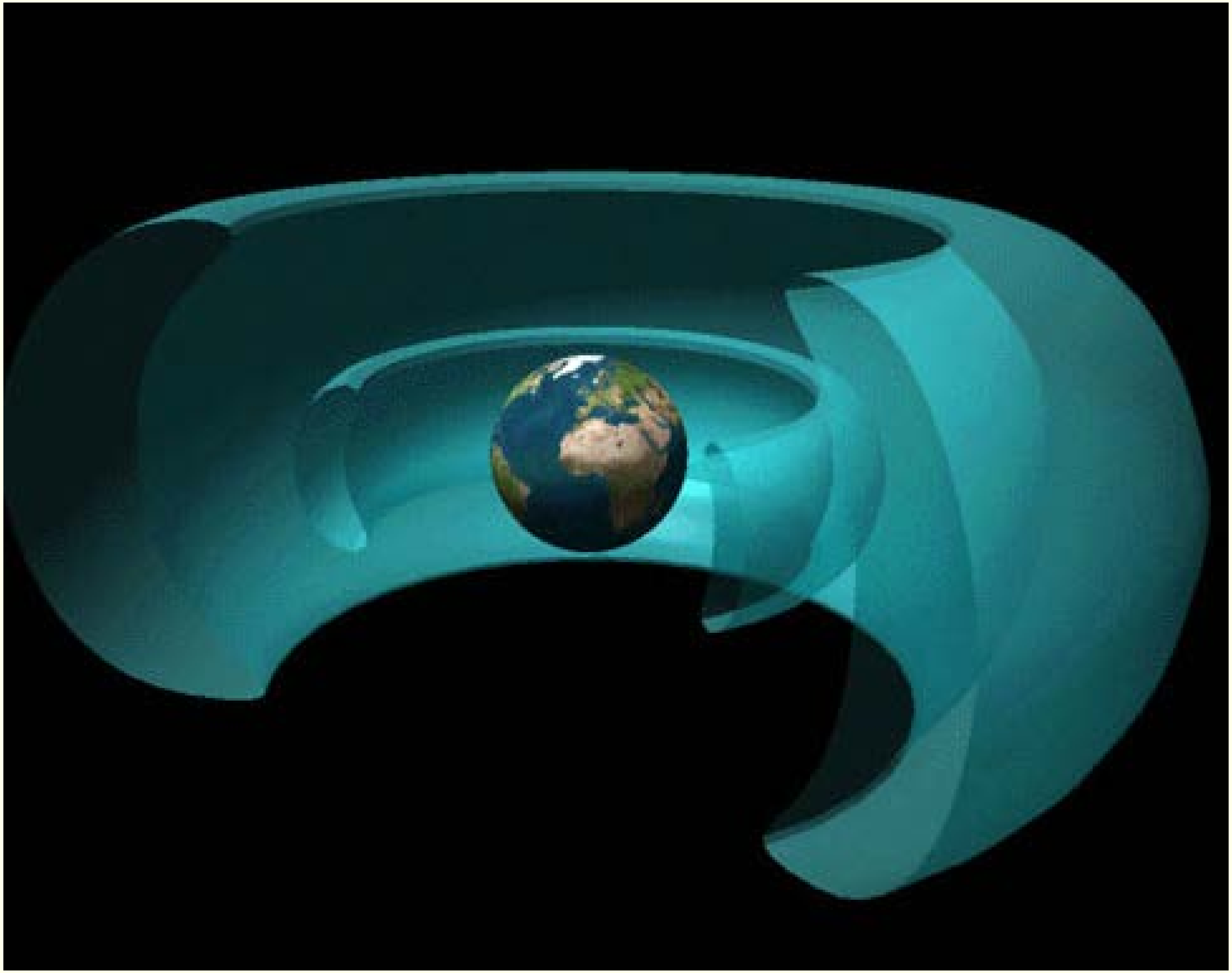



**Figure 8. An illustration of the CRAND process for populating the inner radiation belts [Hess, 1968].**

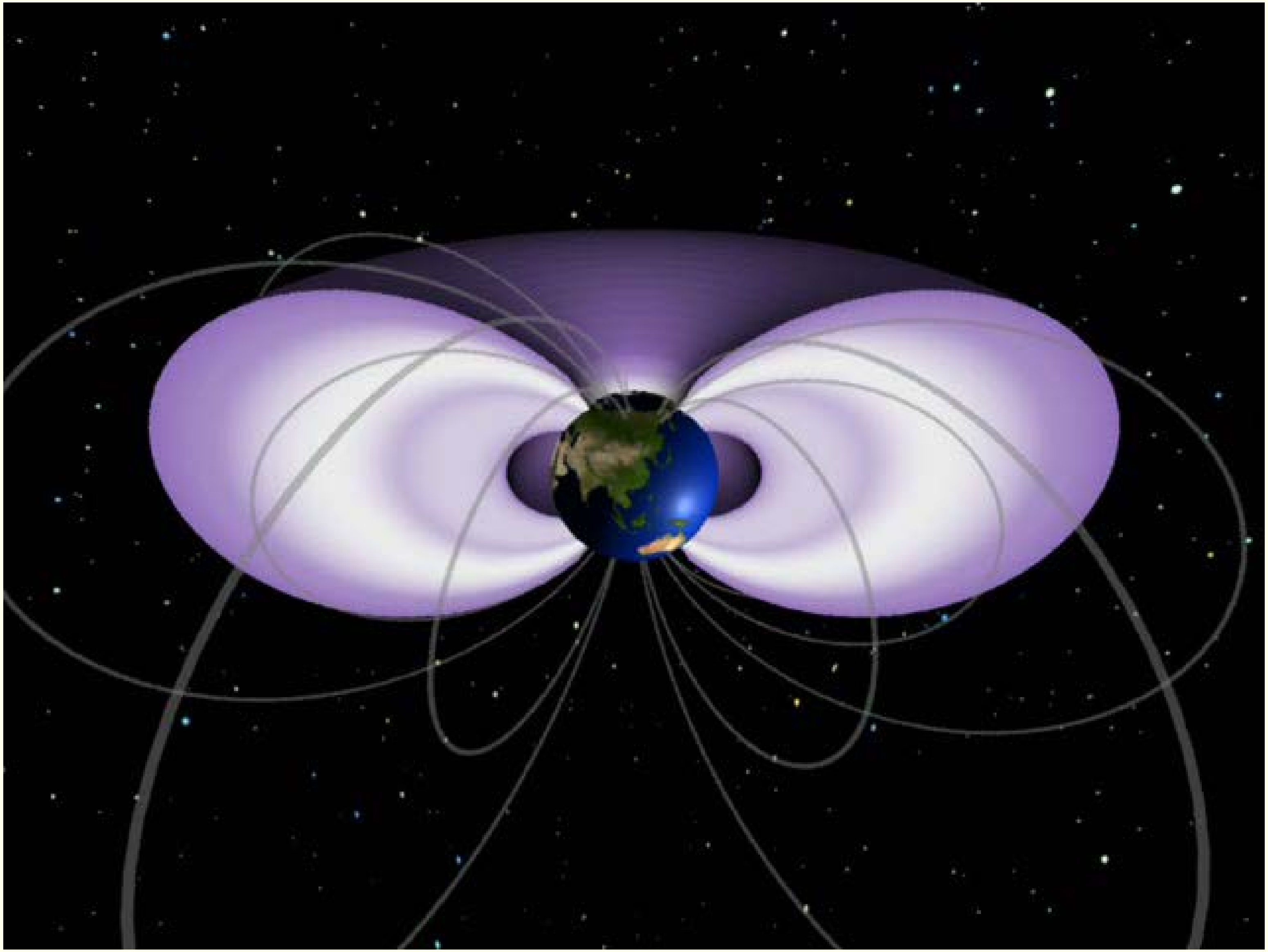
Collisions between cosmic ray particles and the Earth create new particles. Among these are neutrons, that are not affected by the magnetic field. They decay, soom eof them when they happen to be in the radiation belts. The resulting protons and electrons are trapped in the radiation belts.

This contribution to the radiation belts are called the ***neutron albedo***.

# Radiation belts



# Radiation belts

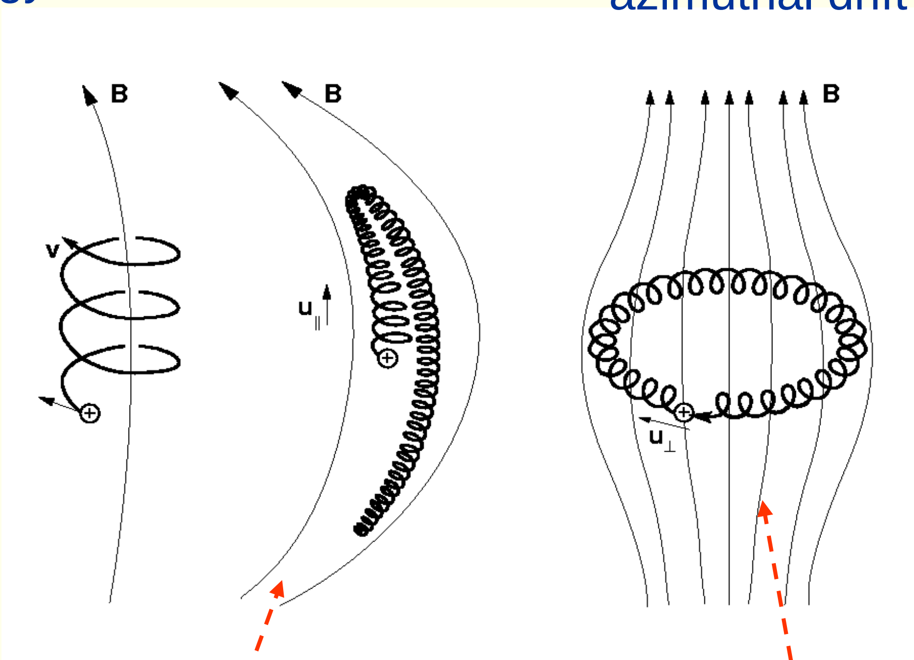


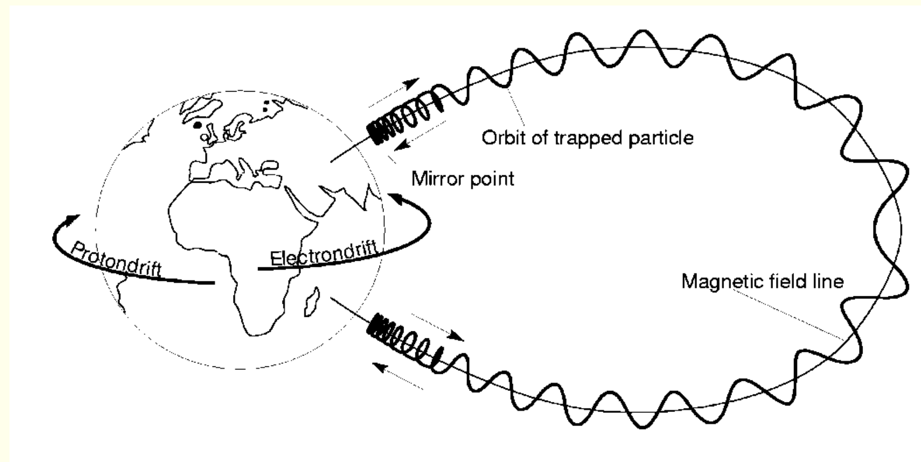
# Particle motion in geomagnetic field

longitudinal oscillation

gyration

azimuthal drift

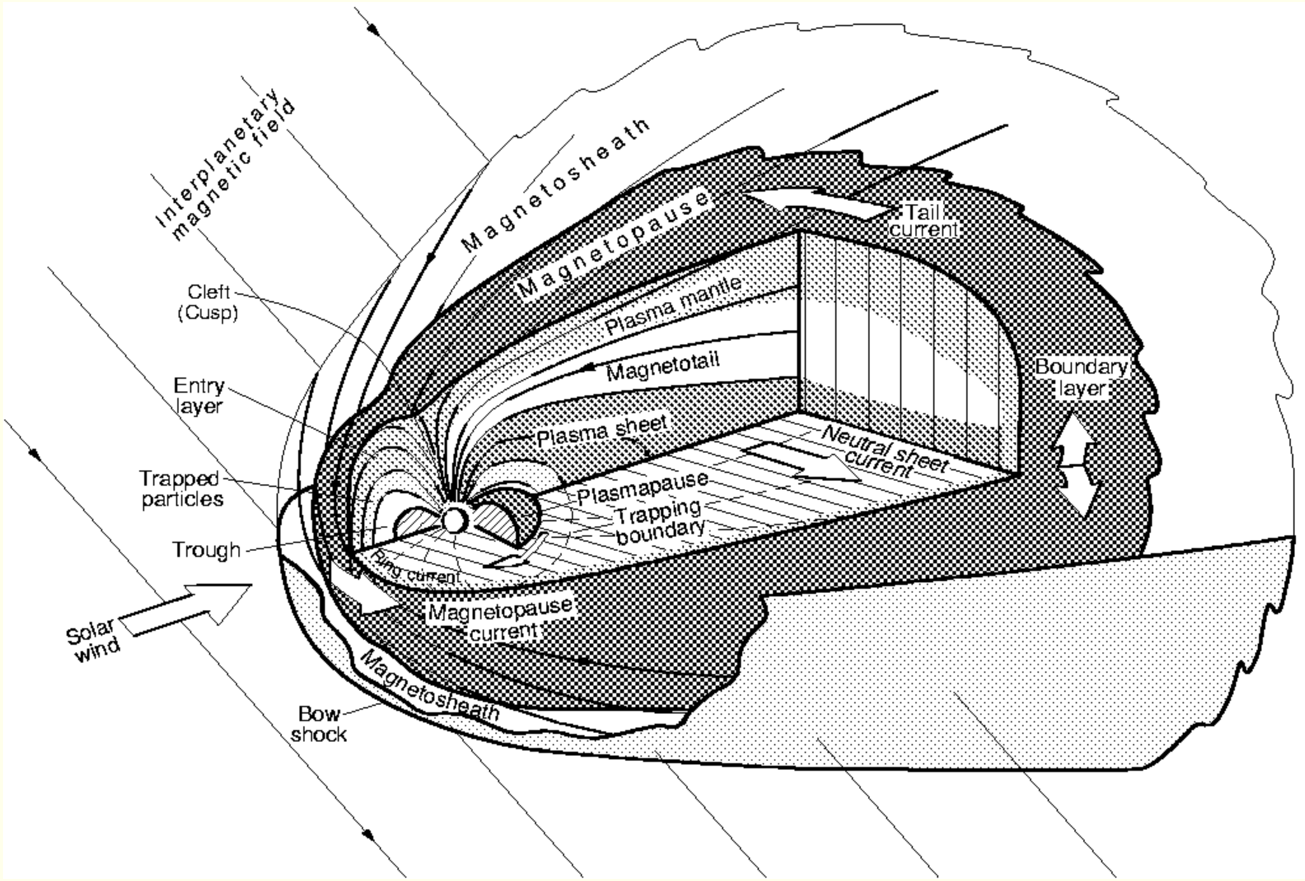



Magnetic mirror

grad B drift

# Structure of magnetosphere

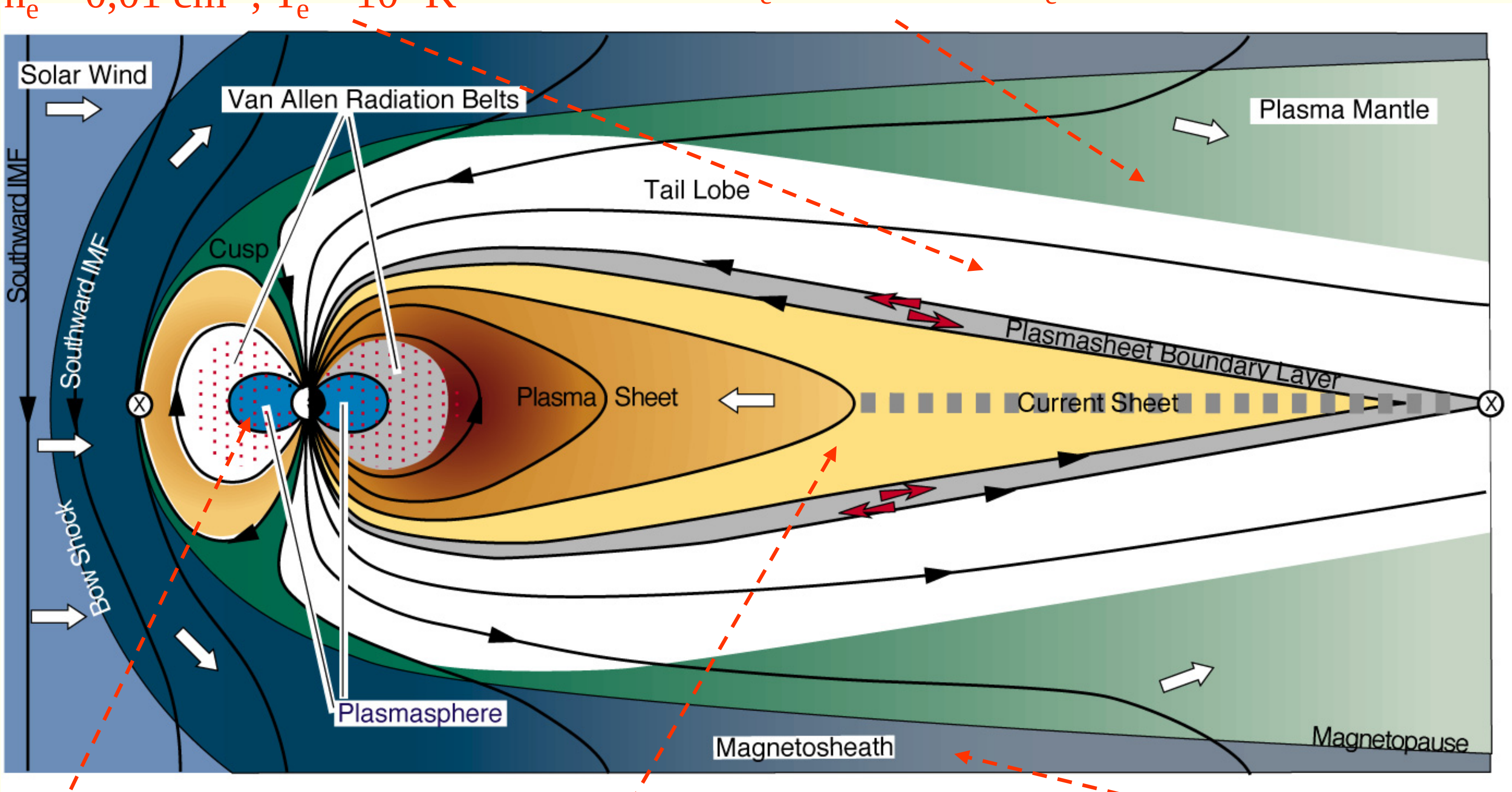



- The plasma in the is made up of approximately equal parts of $H^+$ and $O^+$.
- Plasma populations organized by geomagnetic field.
- Particles will mirror between northern and southern hemispheres on closed field lines

# Magnetospheric structure

polar plumes = tail lobe
$n_e \sim 0{,}01\ cm^{-3}$, $T_e \sim 10^6$ K

plasma mantle
$n_e \sim 0{,}1\text{-}1\ cm^{-3}$, $T_e \sim 10^6$ K

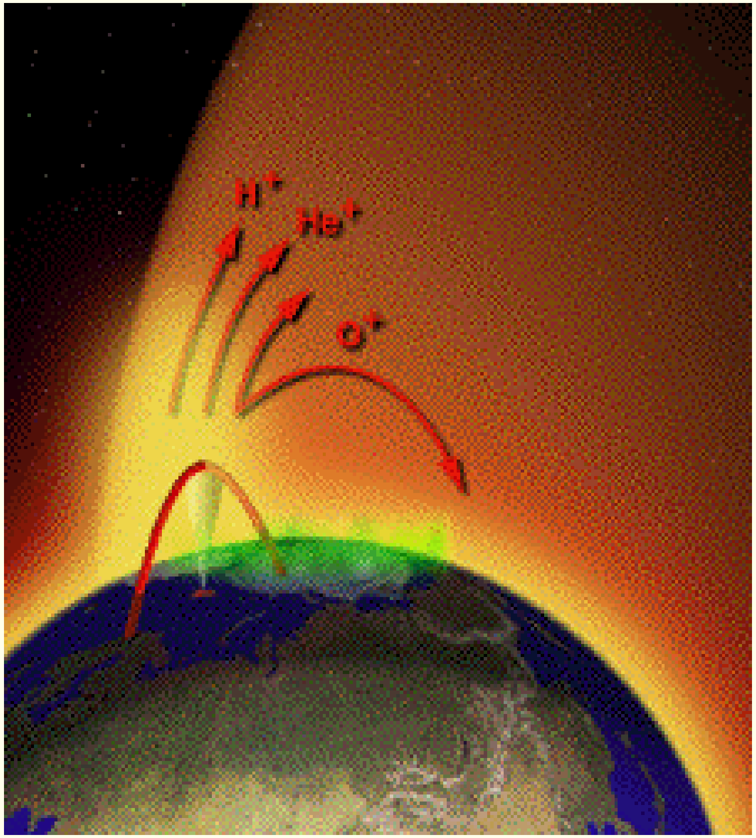



plasmasphere:
$n_e \sim 10\text{-}100\ cm^{-3}$, $T_e \sim 1000$ K

plasma sheet:
$n_e \sim 1\ cm^{-3}$, $T_e \sim 10^7$ K

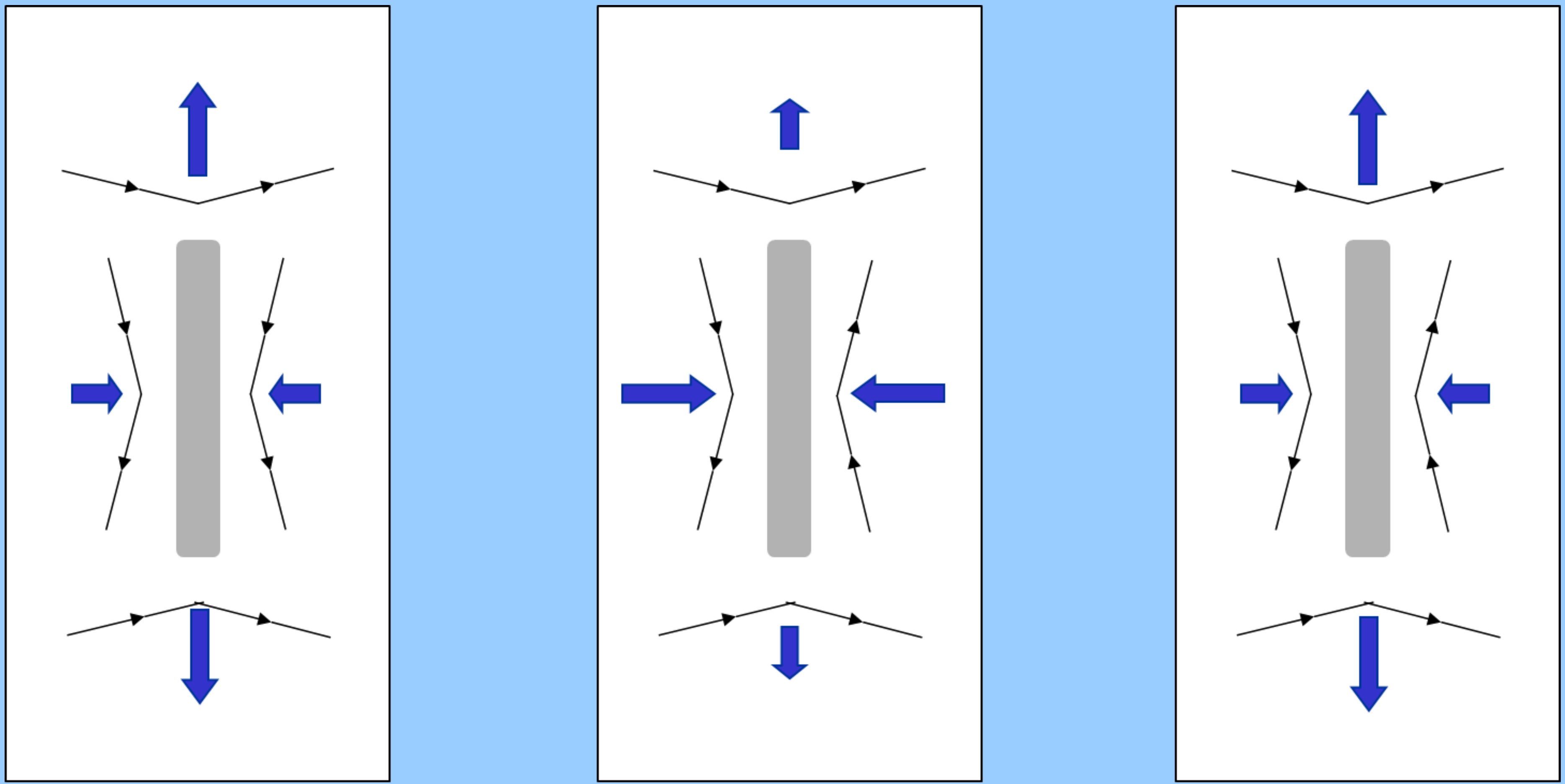
magnetosheath:
$n_e \sim 5\ cm^{-3}$, $T_e \sim 10^6$ K

# Outflow from the ionosphere



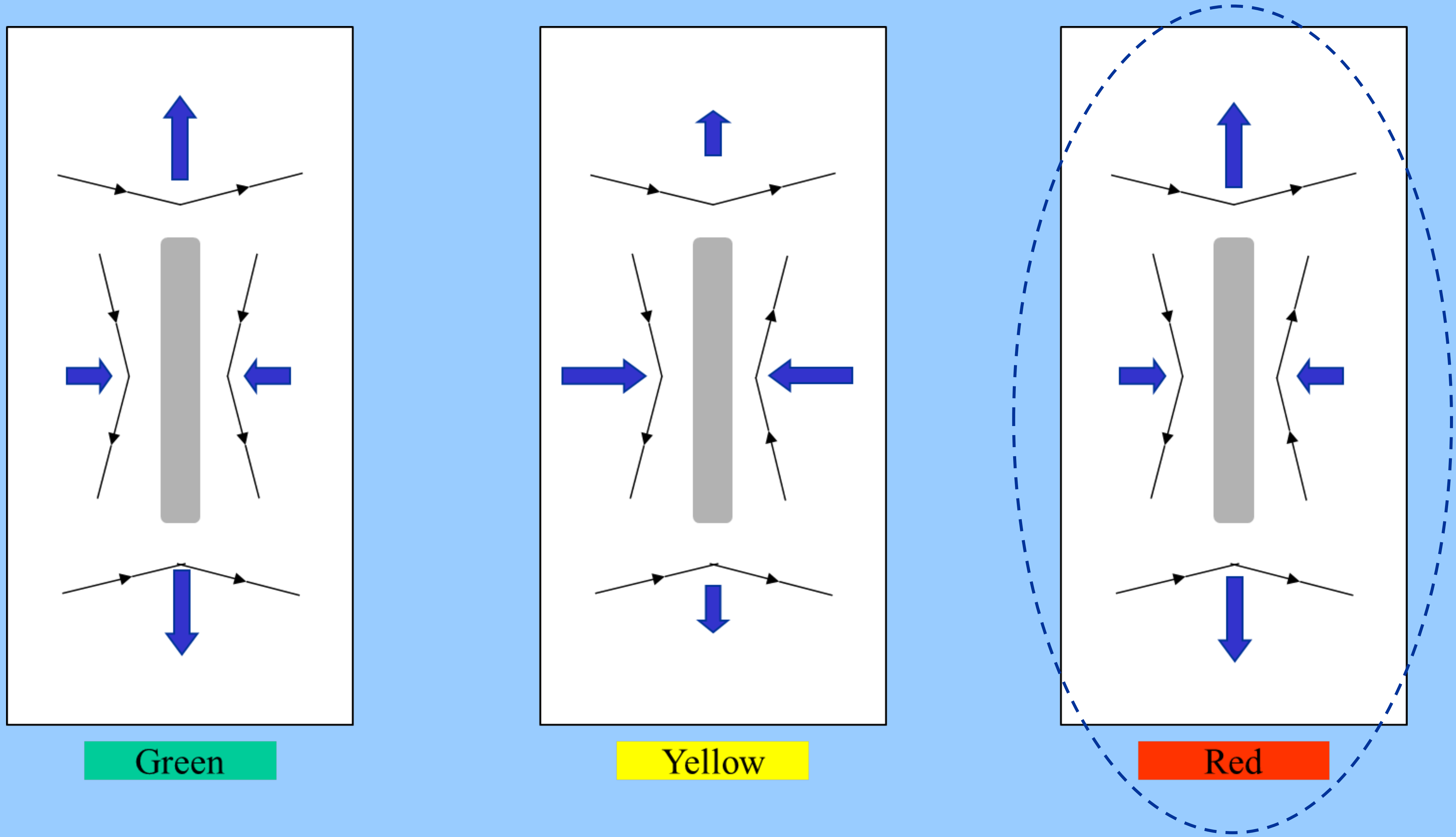

An important source for the magnetospheric plasma. Research is ongoing.

# Magnetic reconnection

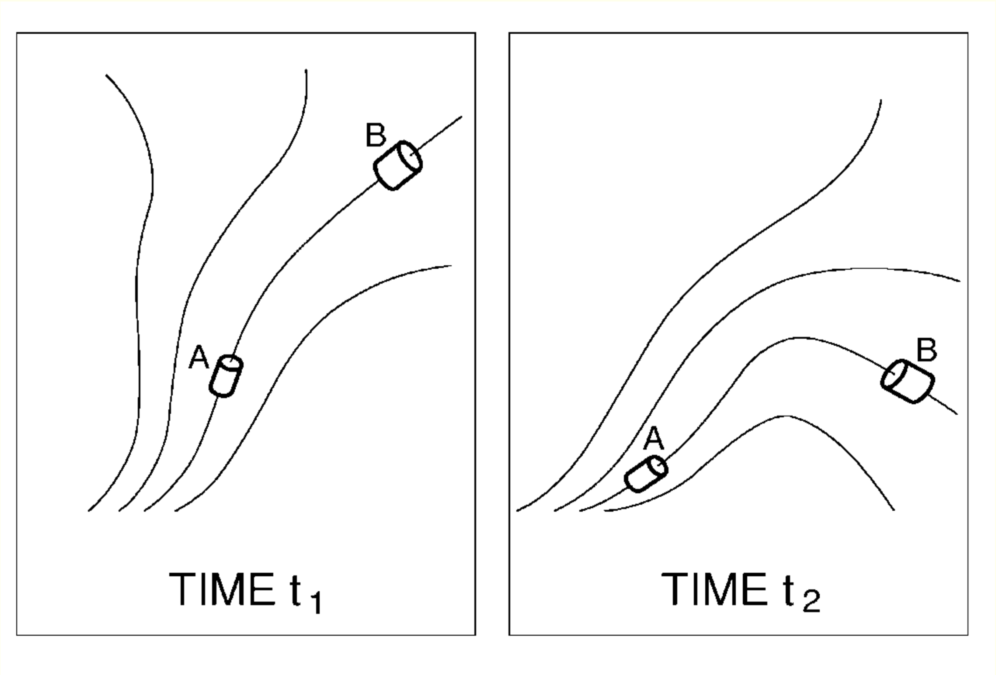


Green | Yellow | Red

# Magnetic reconnection



# Frozen in magnetic field lines



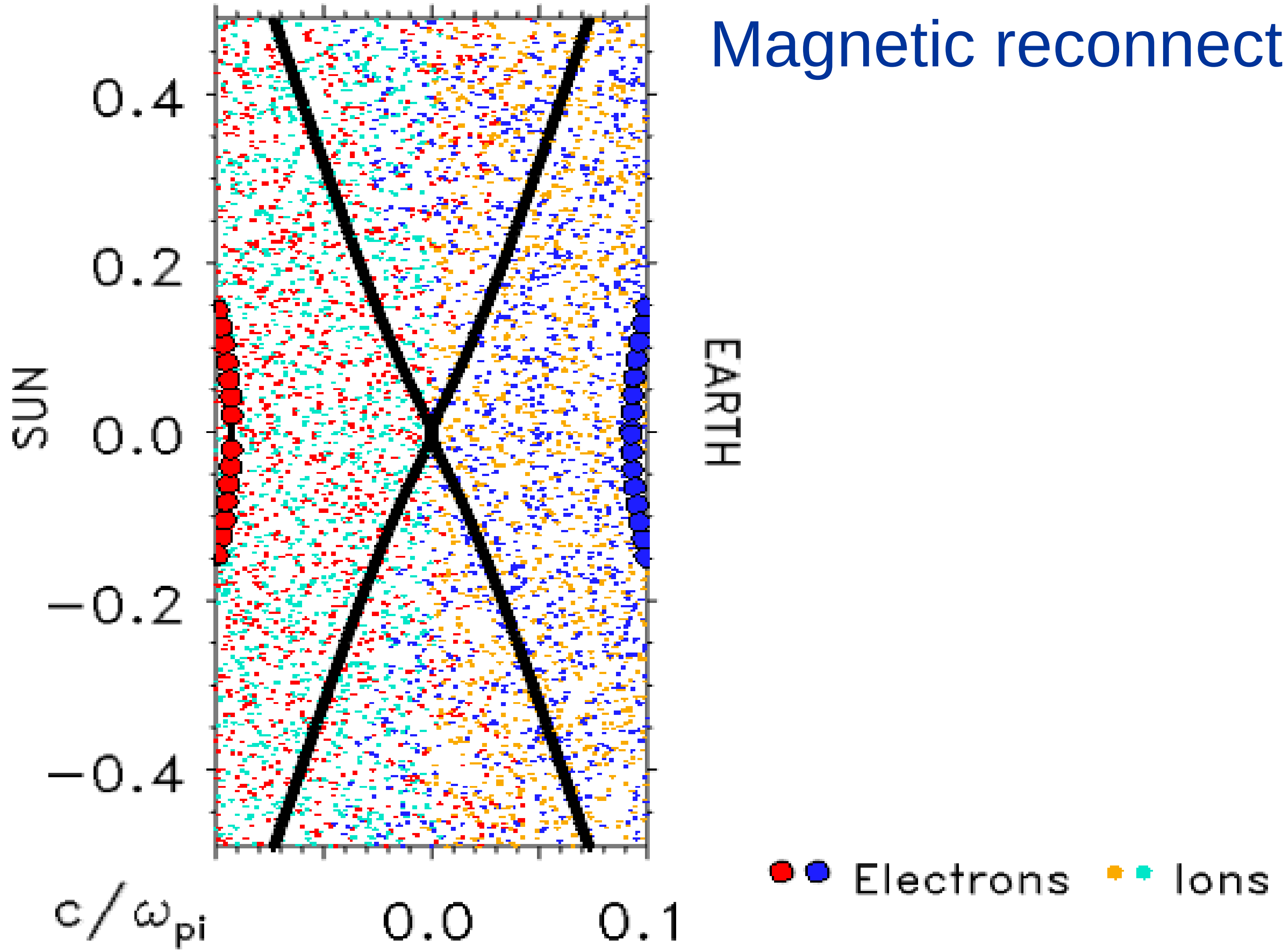

In fluid description of plasma two plasma elements that are connected by a common magnetic field line at time $t_1$ will be so at any other time $t_2$.

This applies if the magnetic Reynolds number is large:

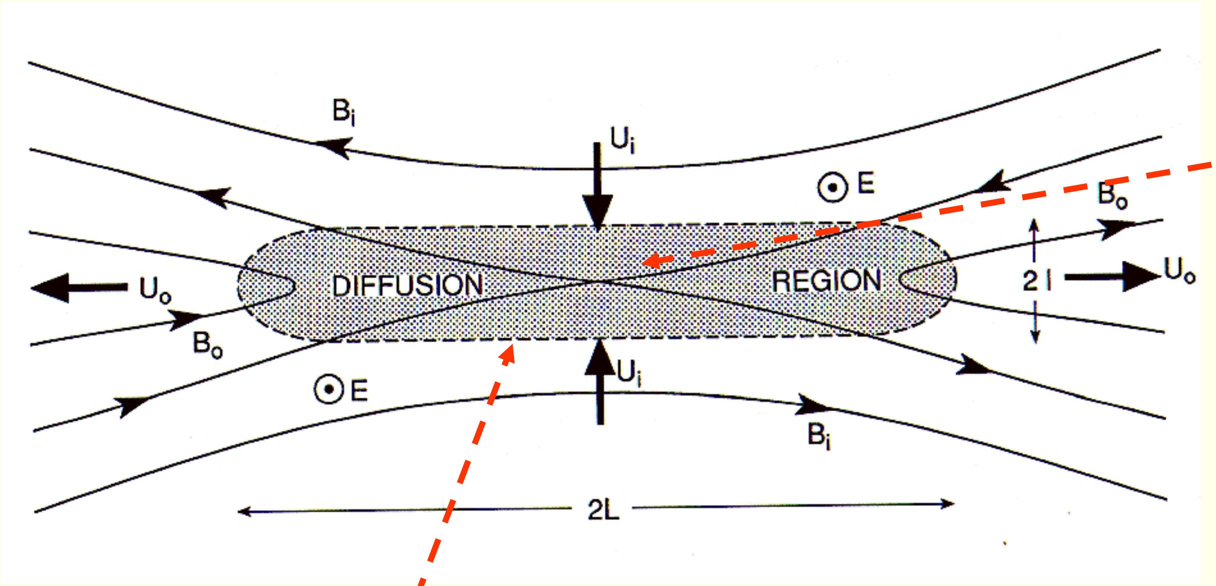
$$R_m = \mu_0 \sigma l_c v_c >> 1$$

***An example of the collective behaviour of plasmas.***

# Magnetic reconnection



# Reconnection




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

In 'diffusion region':

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

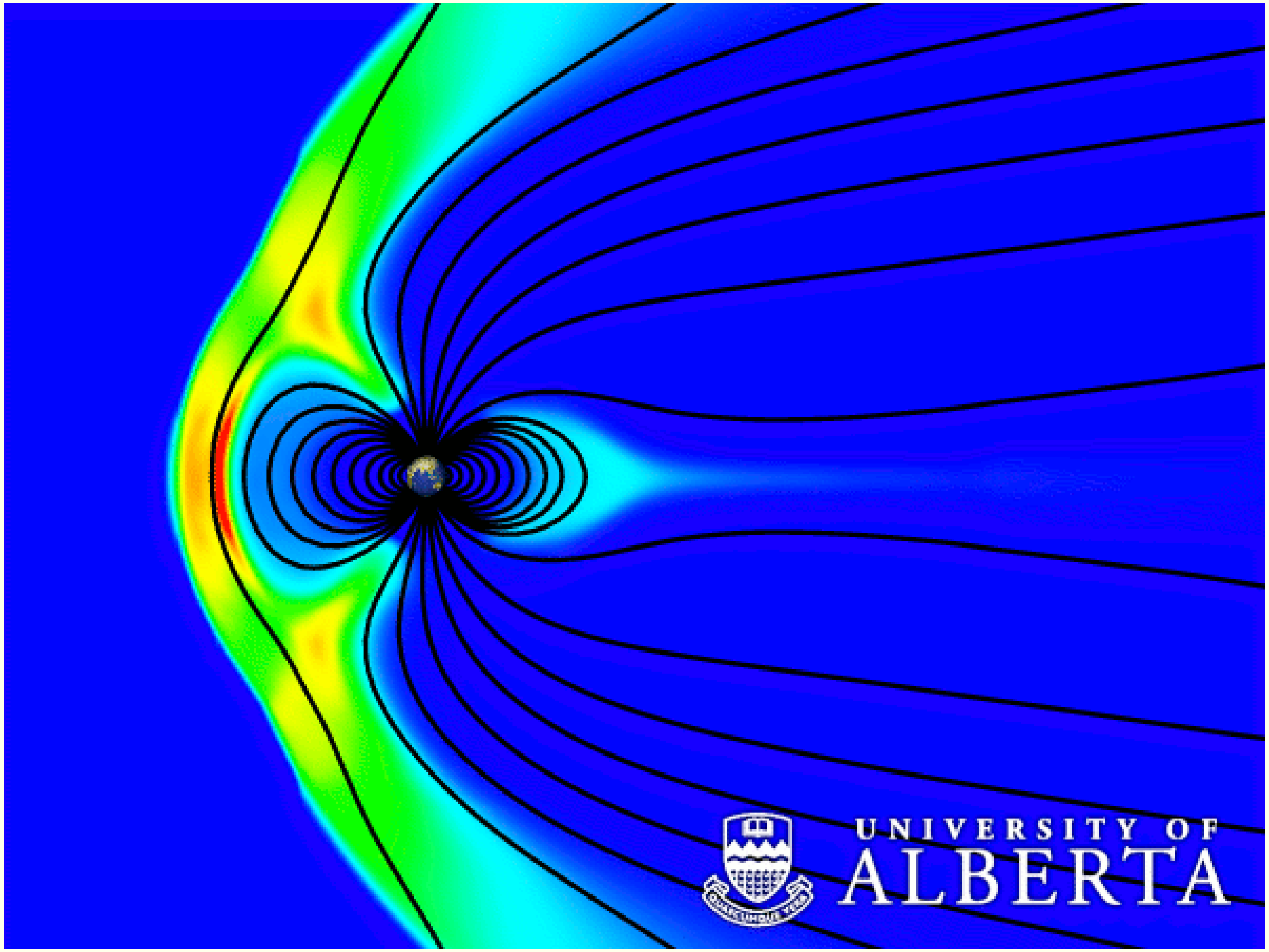
Thus: condition for frozen-in magnetic field breaks down.

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

- **Plasma from different field lines can mix**

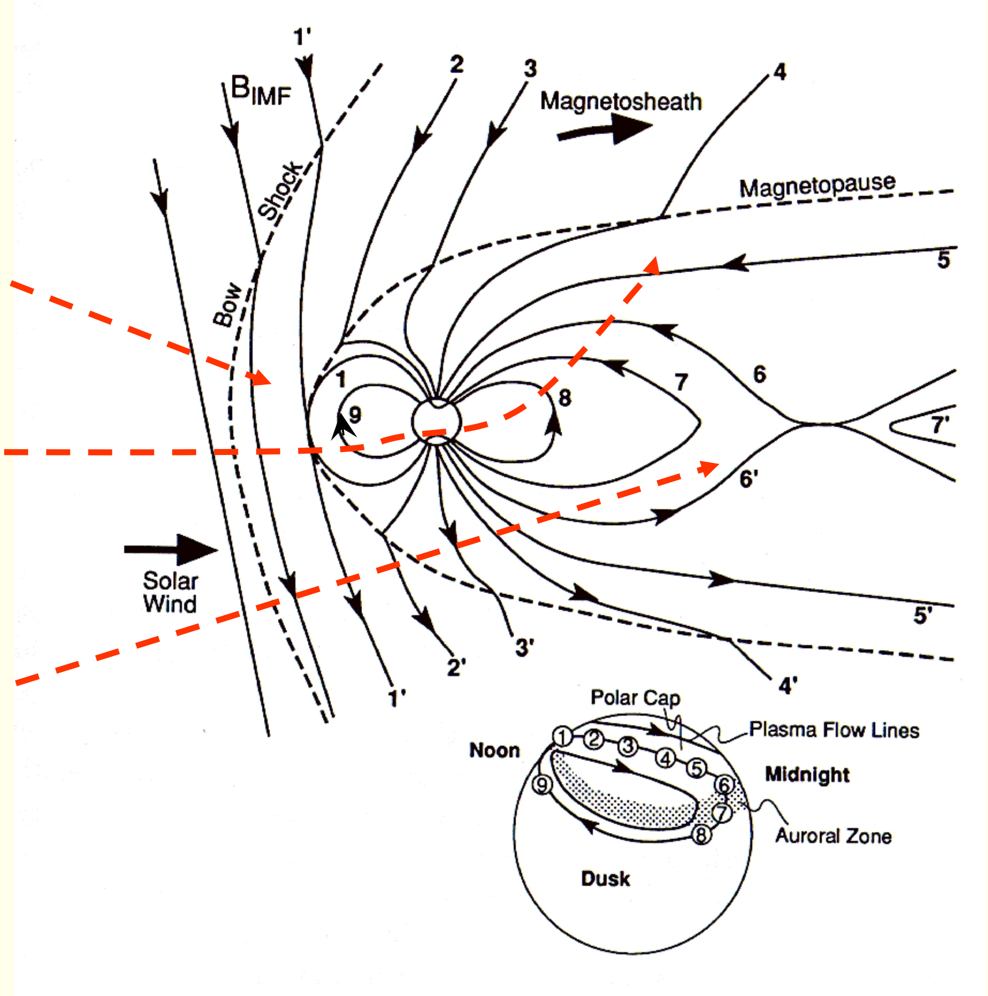
# Reconnection and plasma convection

Solar wind

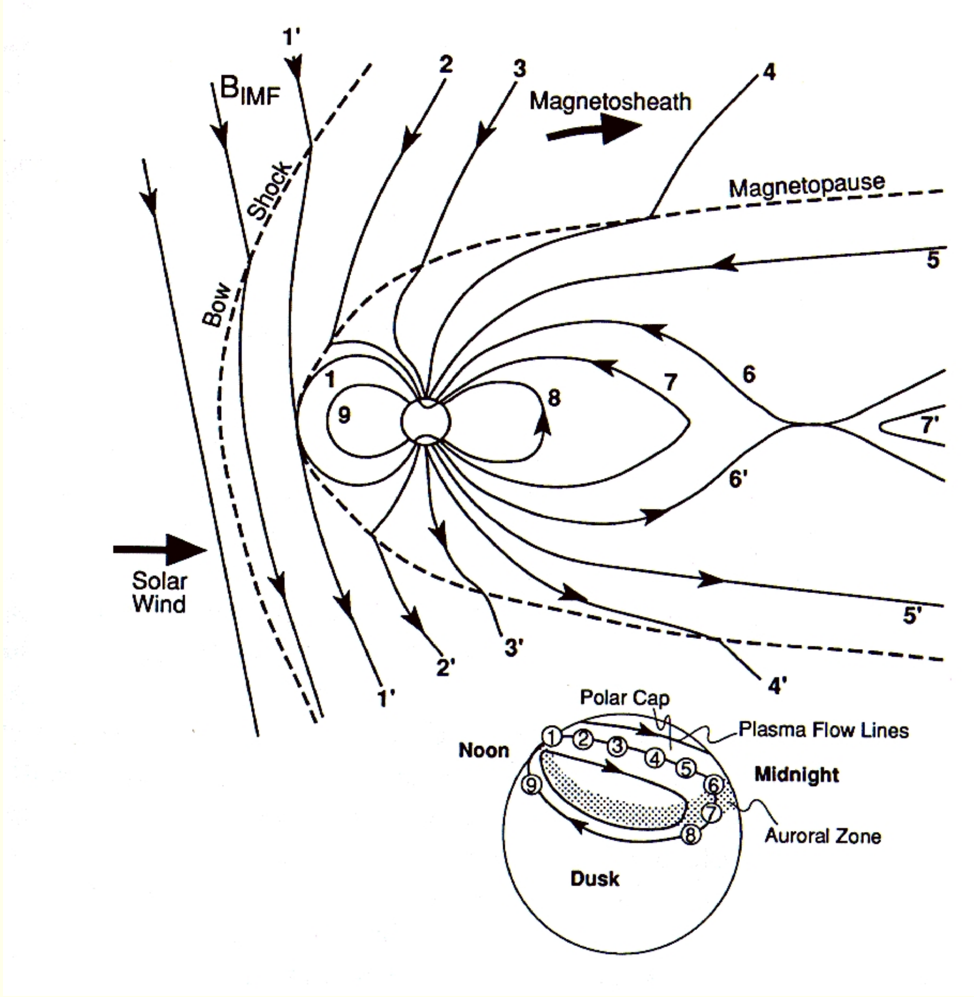


# Reconnection och plasma convection

- Reconnection on the dayside "re-connects" the solar wind magnetic field and the geomagnetic field
- In this way the plasma convection in the outer magnetosphere is driven
- In the night side a second reconnection region drives the convection in the inner magnetosphere.
  The reconnection also heats the plasmasheet plasma.

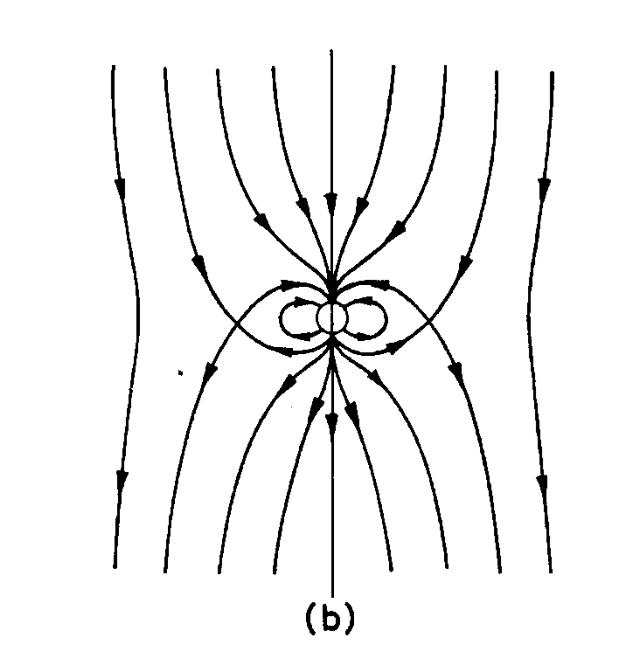


# What happens if IMF is northward instead?

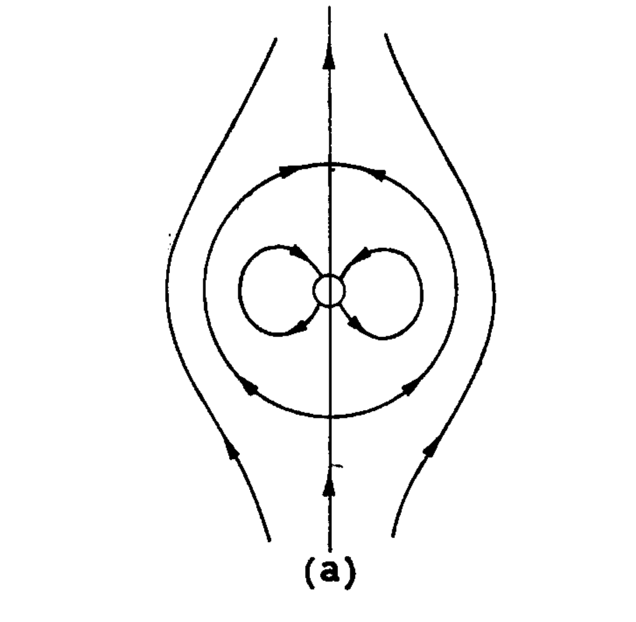


# Magnetospheric dynamics

*open magnetosphere*




*closed magnetosphere*




southward

Interplanetary magnetic field (IMF)

northward

# What do the magnetospheres of the other planets look like?

# Last Minute!

# Last Minute!

- What was the most important thing of today's lecture? Why?
- What was the most unclear or difficult thing of today's lecture, and why?
- Other comments