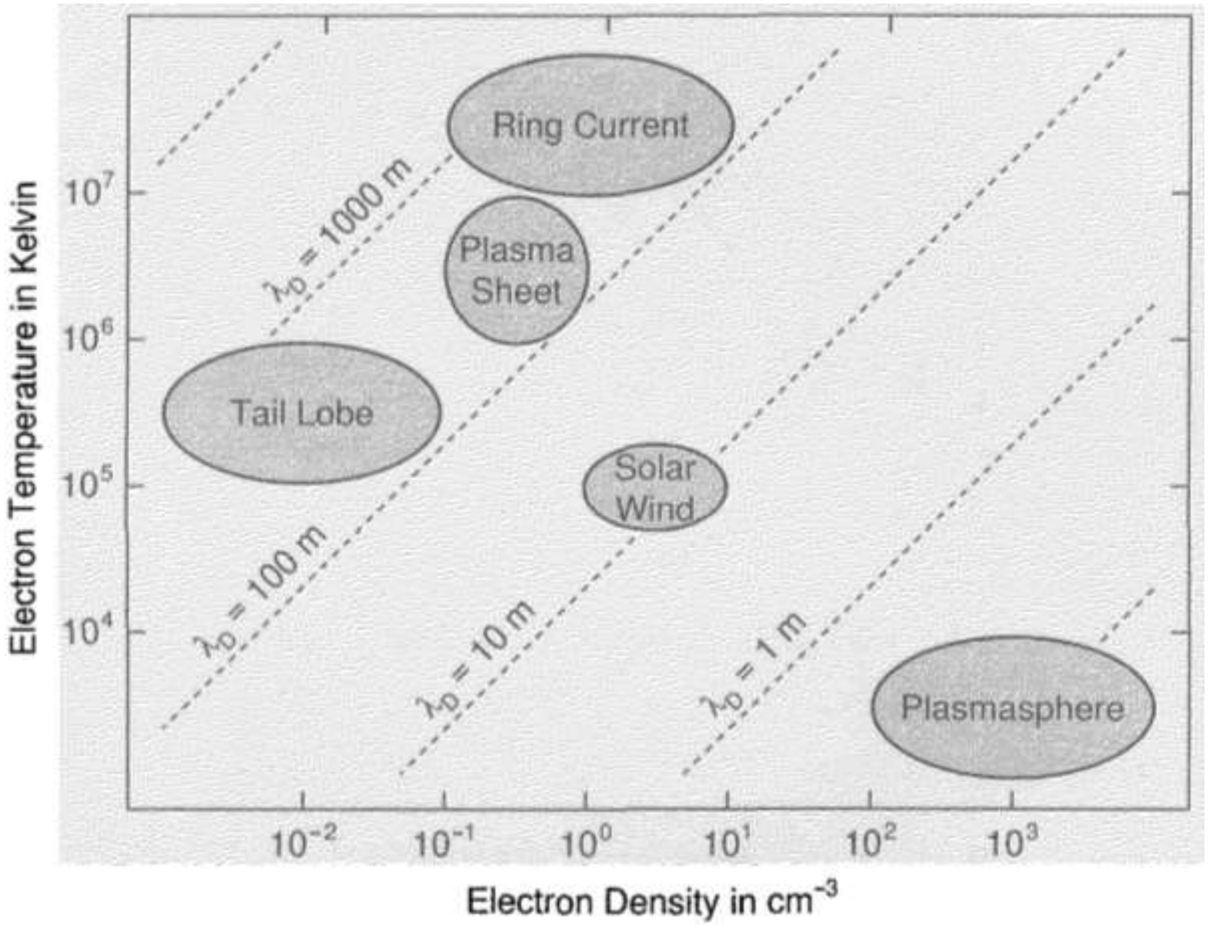
Basic plasma physics

Further reading:
Baumjohann & Treumann book, Ch. 1-2

Definition of plasma

- A gas of free quasi-neutral positive/negative particles.
- Freedom: thermal kinetic energy greater than potential energy, ~eV (1eV ~ 10^4 K).
- By far the most common state, some 99% of all matter.
- Examples of geophysical plasmas.



Large enough scale (1st plasma criteria)

- Due to neutralising effects of opposite charges, the electric potential is statistically cancelled at certain distance.

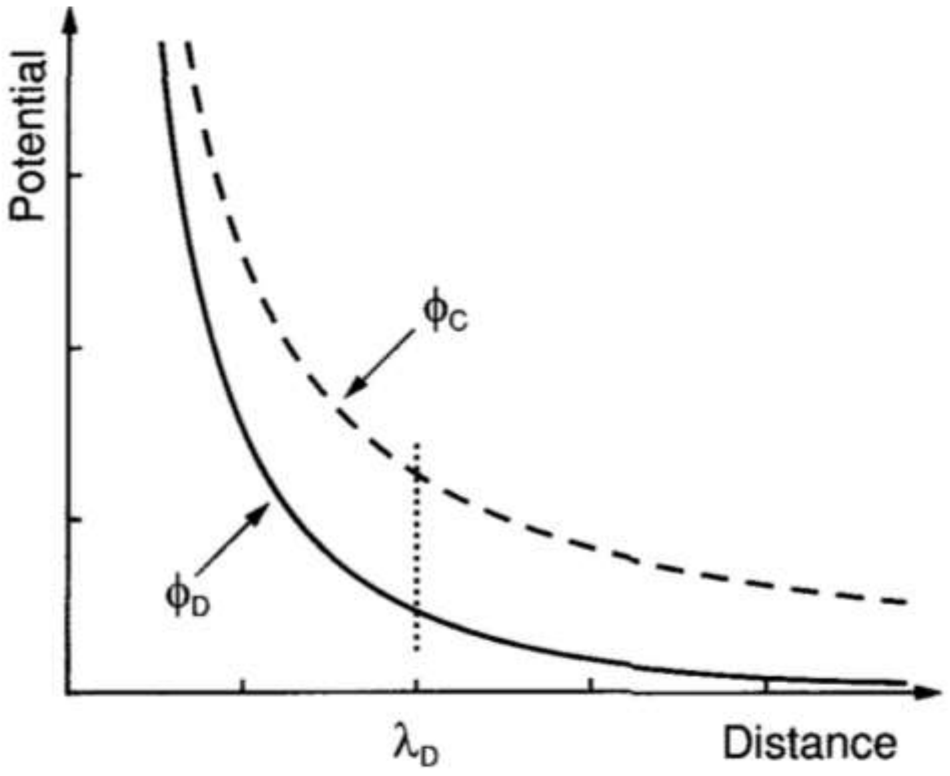
Debye length

$$\lambda_D = \left(\frac{\epsilon_0 k_B T_e}{n_e e^2} \right)^{1/2}$$

- Gas behaves as quasi-neutral plasma on scales greater than Debye length

$$\lambda_D \ll L$$

Coulomb vs Debye potential



Enough ionised particles (2nd plasma criteria)

- There should be enough particles inside the “Debye sphere”, otherwise no shielding occurs.

Plasma parameter $\Lambda = n_e \lambda_D^3 \gg 1$

- If the plasma equilibrium is externally disturbed, free oscillations will occur (electrons will oscillate with respect to ions)

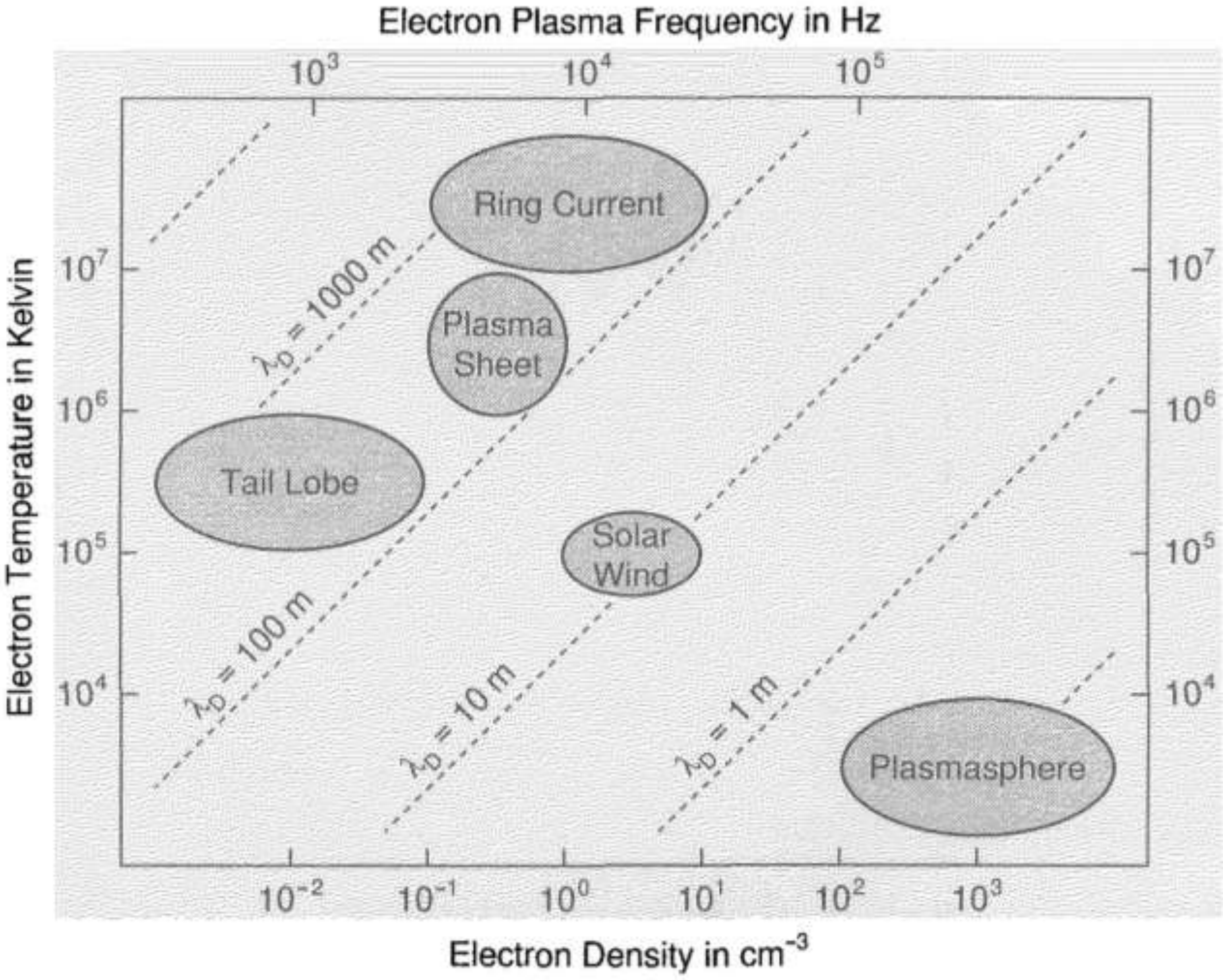
Plasma frequency (free oscillator)

$$\omega_{pe} = \left(\frac{n_e e^2}{m_e \epsilon_0} \right)^{1/2}$$

Not too many neutrals (3rd plasma criteria)

- Electron will not oscillate freely if there are too frequent collisions with neutrals.
- The interval between collision with neutrals should be longer than the plasma oscillation period

$$\omega_{pe}\tau_n \gg 1$$

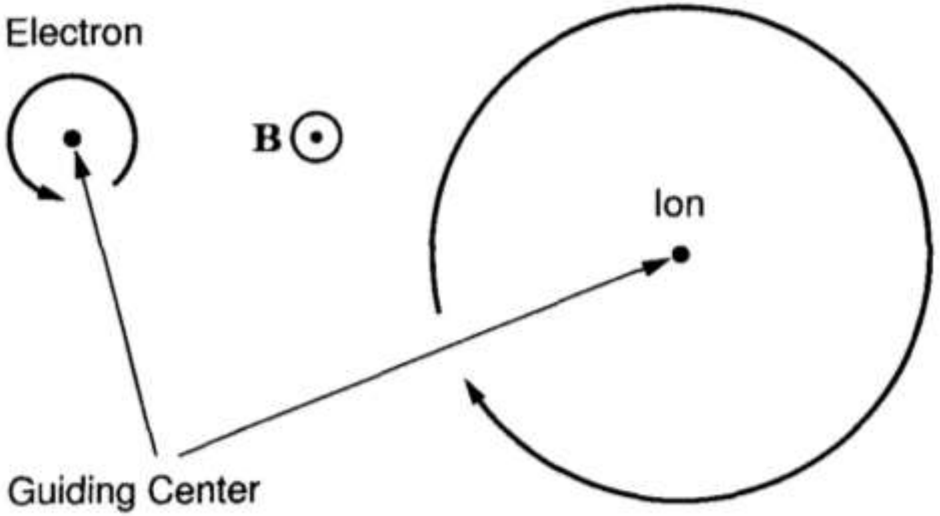


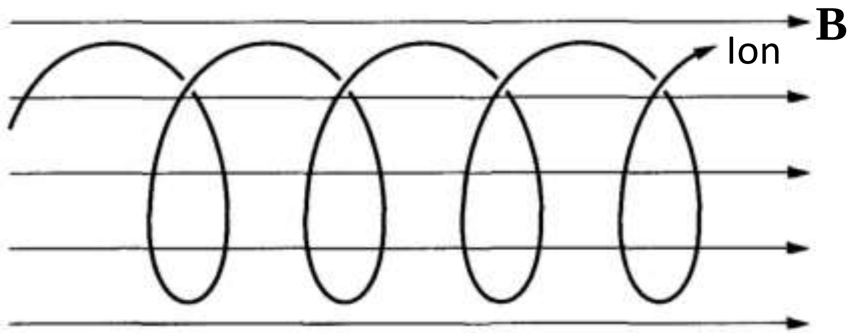
Individual particle motion

- In uniform magnetic field, electrons and ions will gyrate in opposite senses, with ions having larger orbits.

Gyro-frequency $$\omega_g = \frac{qB}{m}$$

- Plasma gyration act as diamagnetic, against an imposed magnetic field.



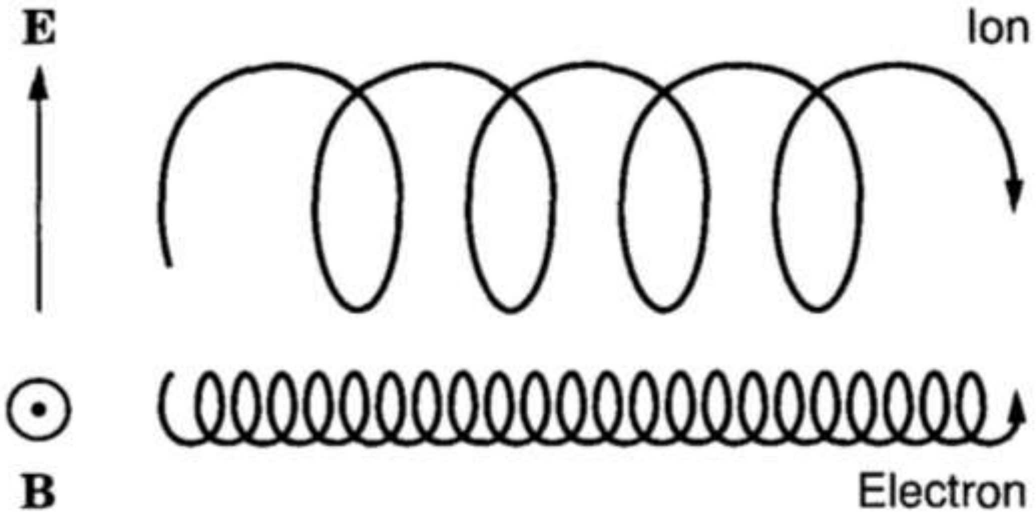


Electric ExB drift under uniform fields

- Under the influence of uniform electric **E** and magnetic **B** fields, both ions and electrons will drift in the same direction.

Guiding centre drift $\mathbf{v}_E = \dfrac{\mathbf{E} \times \mathbf{B}}{B^2}$

In the guiding centre frame $\mathbf{E} = -\mathbf{v} \times \mathbf{B}$



ExB drift yields no net current!

Polarization drift and currents

- For varying electric fields, a correction is needed for the drift

$$\mathbf{v}_d = \mathbf{v}_E + \frac{1}{\omega_g B}\frac{d\mathbf{E}_\perp}{dt}$$

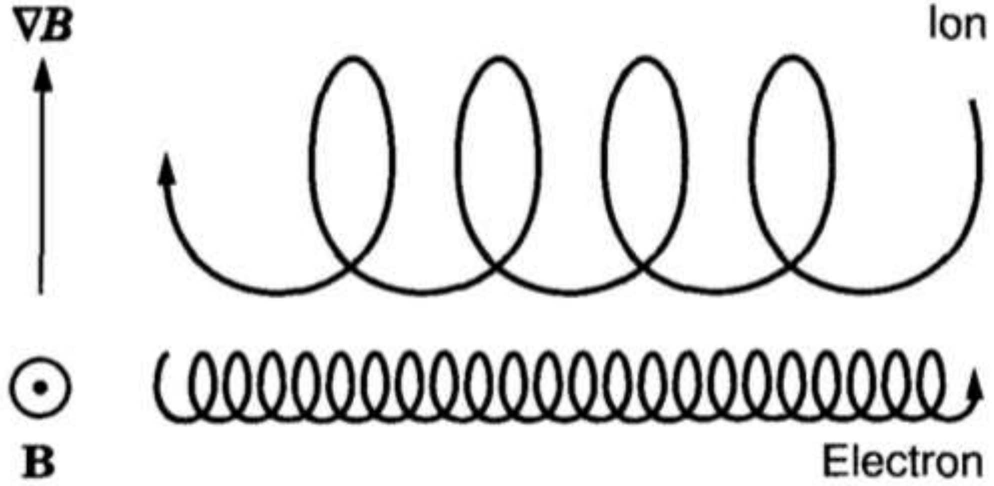
- Ions and electrons no longer drift the same, yielding the polarisation current

$$\mathbf{j}_P = n_e e\,(\mathbf{v}_{Pi} - \mathbf{v}_{Pe}) = \frac{n_e(m_i + m_e)}{B^2}\frac{d\mathbf{E}_\perp}{dt}$$

- Polarisation current is mainly carried by ions.

Magnetic drifts

- For non-uniform magnetic fields, more drift corrections are needed, leading to extra drifts and currents

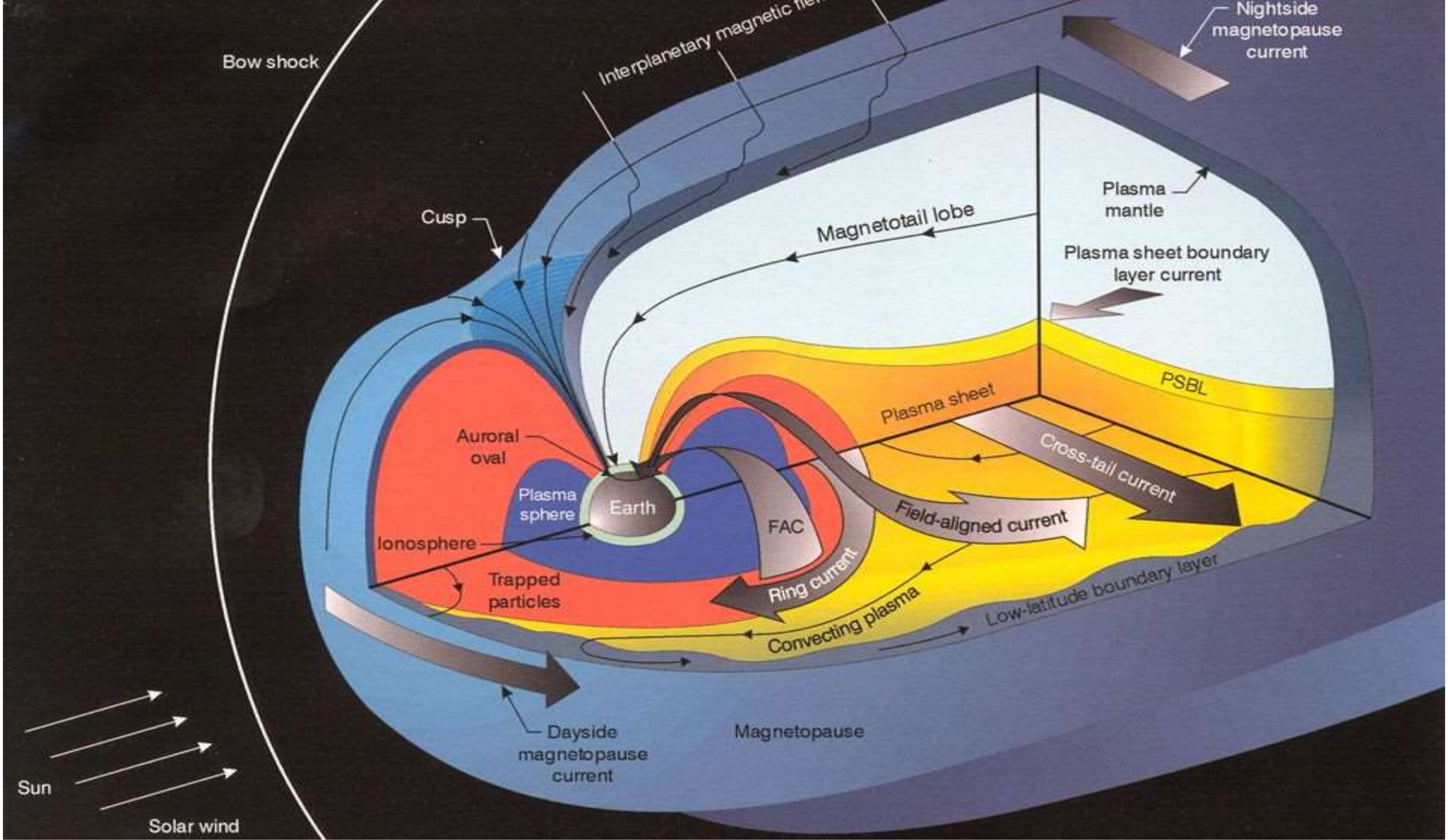


Gradient drift

$$\mathbf{v}_\nabla = \frac{m v_\perp^2}{2 q B^3} (\mathbf{B} \times \nabla B)$$

Gradient current

$$\mathbf{j}_\nabla = n_e e\,(\mathbf{v}_{\nabla i} - \mathbf{v}_{\nabla e}) = \frac{n_e(\mu_i + \mu_e)}{B^2}\,\mathbf{B} \times \nabla B$$



Bow shock
Interplanetary magnetic field
Nightside magnetopause current
Plasma mantle
Magnetotail lobe
Cusp
Plasma sheet boundary layer current
PSBL
Plasma sheet
Auroral oval
Cross-tail current
Plasma sphere
Earth
FAC
Field-aligned current
Ionosphere
Ring current
Low-latitude boundary layer
Trapped particles
Convecting plasma
Dayside magnetopause current
Magnetopause
Sun
Solar wind