Last lecture (6)

- Drift motion
- Ionospheric conductivities
- Particle motion in the magnetosphere

Today's lecture (7)

- Other magnetospheres
- Aurora
- Current measurements in space

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

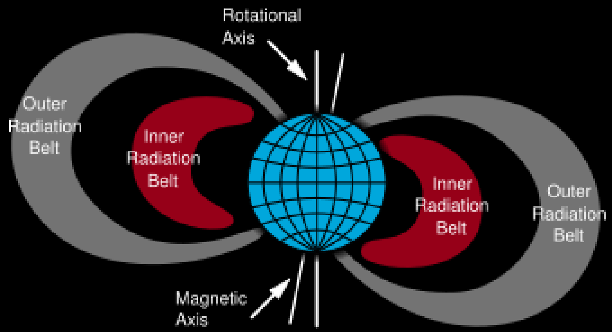
- shocks and boundaries in space
- solar wind interaction with magnetized and unmagnetized bodies
- reconnection
- sources of magnetospheric plasma
- magnetospheric and ionospheric convection
- auroral physics
- storms and substorms
- global oscillations of the magnetosphere

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



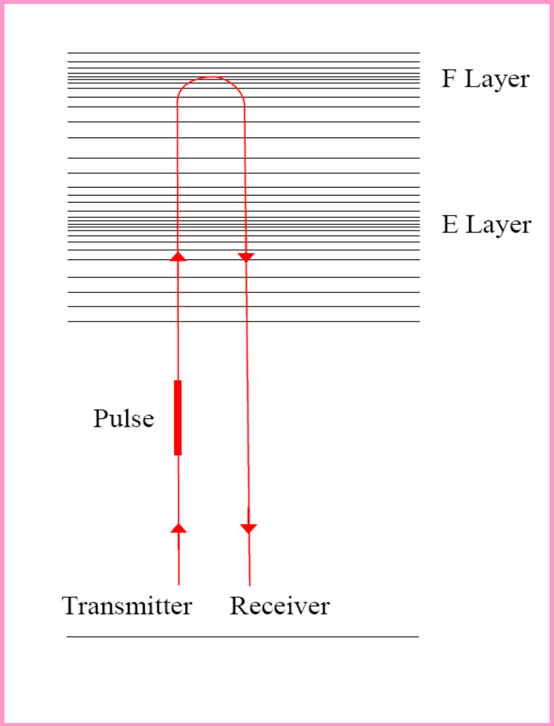
Radiation environment in near-earth space

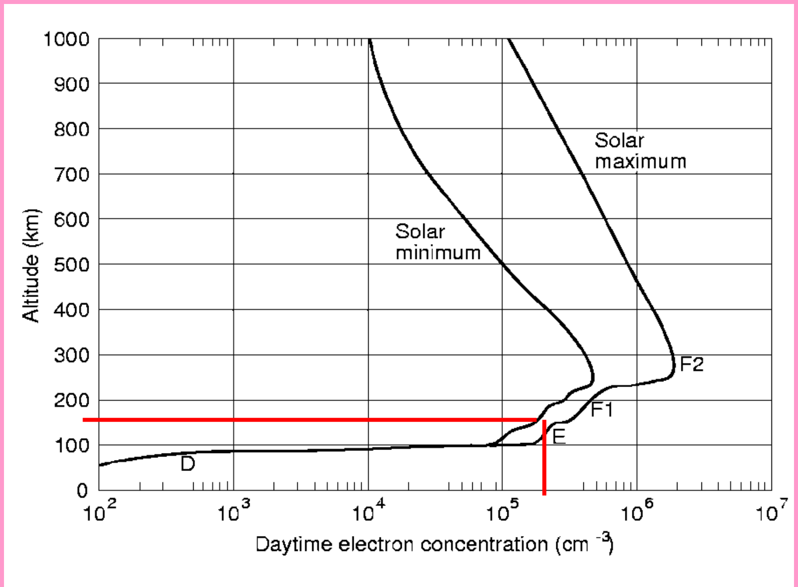
Projects:

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

Mini-groupwork 3

b)





$$f_p = \frac{1}{2\pi}\sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}} \approx 9\sqrt{n_e}$$

$$f_p = 5\cdot 10^6 = 9\sqrt{n_e}$$

$$\Rightarrow$$

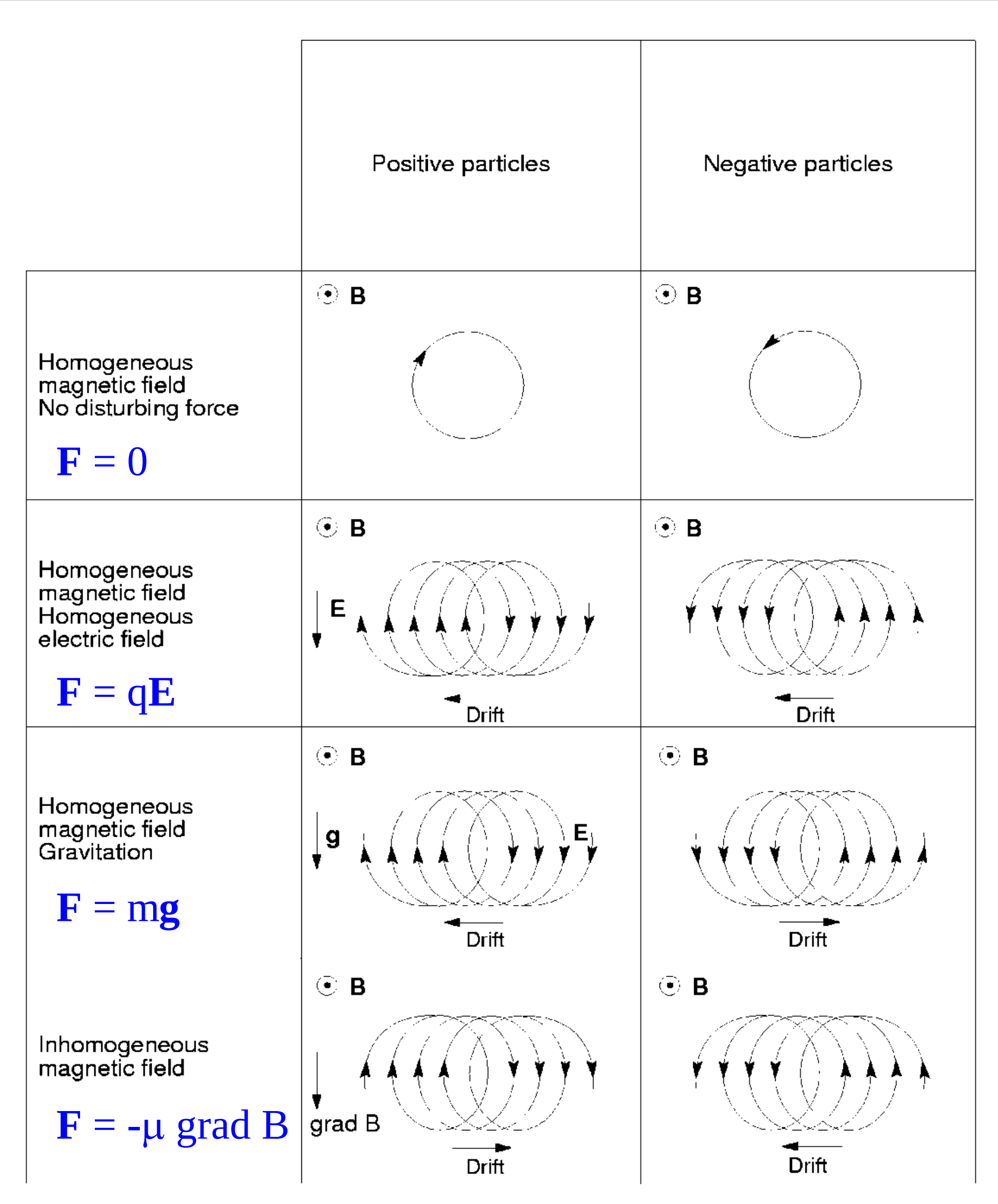
$$n_e = \left(\frac{5\cdot 10^6}{9}\right)^2 = 3\cdot 10^{11} m^{-3}$$

$$h = 150\ km$$

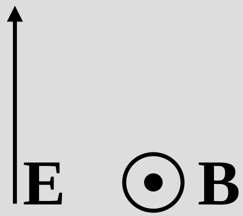
$$t = \frac{2h}{c} = \frac{300\cdot 10^3}{3\cdot 10^8} = 10^{-3} s$$

Drift motion

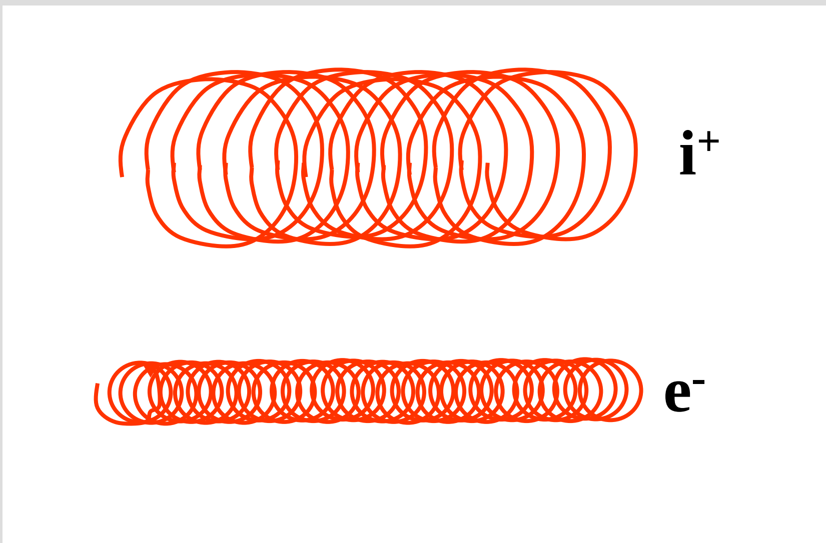
$$\mathbf{u}_{drift} = \frac{\mathbf{F} \times \mathbf{B}}{qB^2}$$



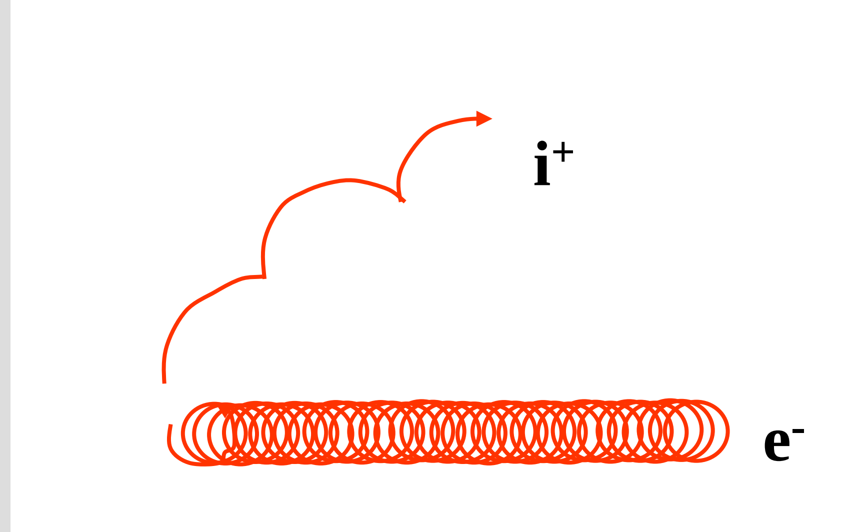
ExB-drift



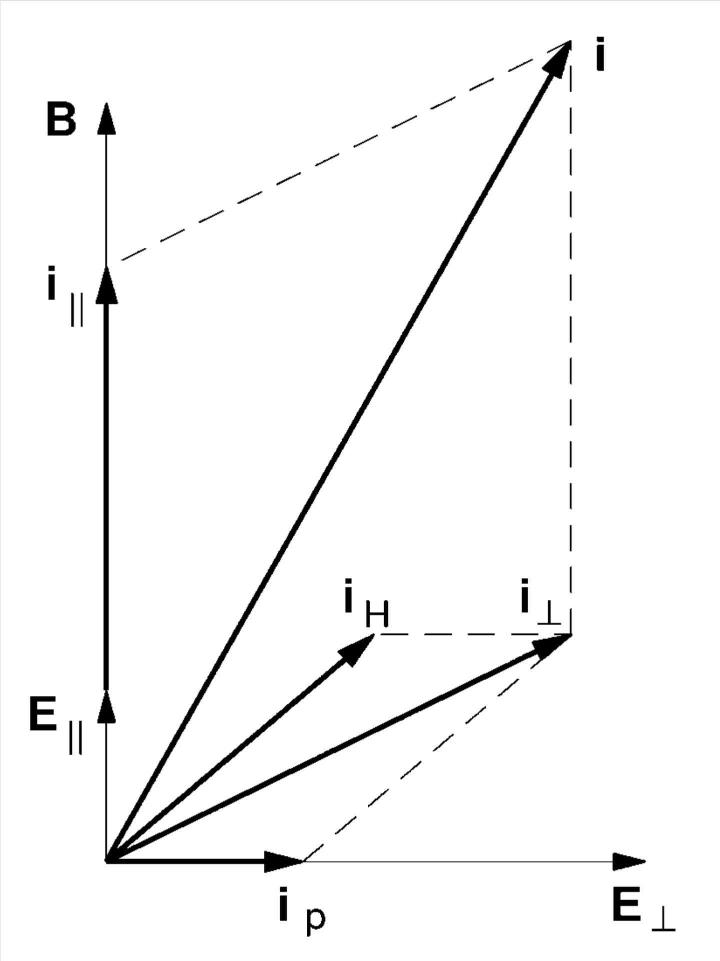
Without collisions



With collisions

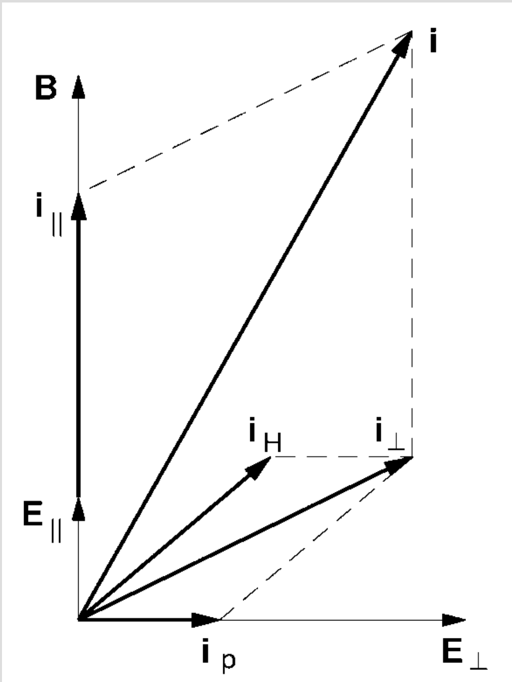


Electric conductivity in a magnetized plasma



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

Electric conductivity in a magnetized plasma II



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

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

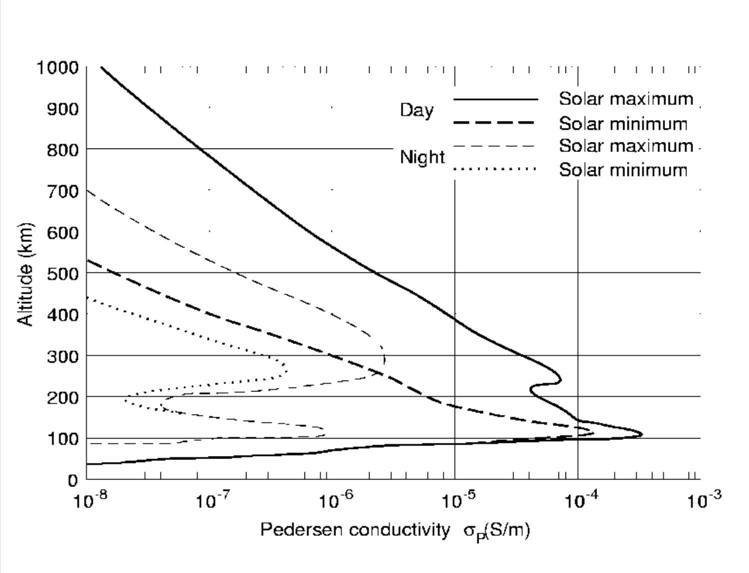
$$\sigma_{//} = \sigma_e + \sigma_i$$

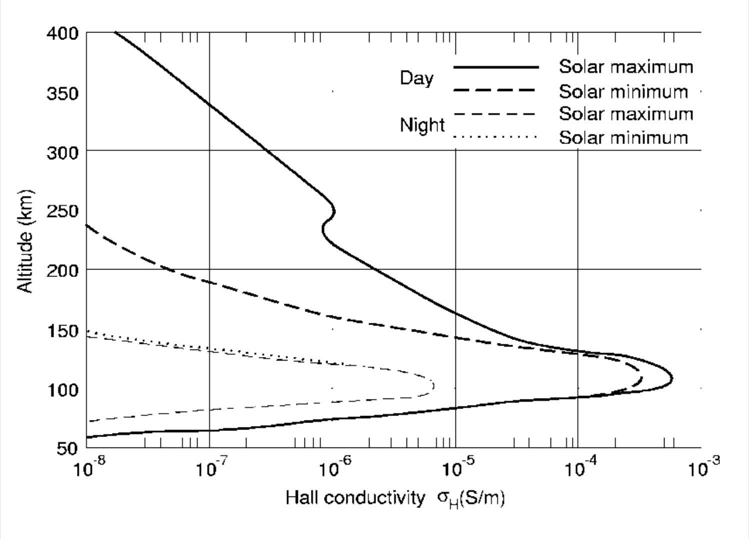
$$\sigma_e = e^2 n\tau_e / m_e \qquad \sigma_i = e^2 n\tau_i / m_i$$

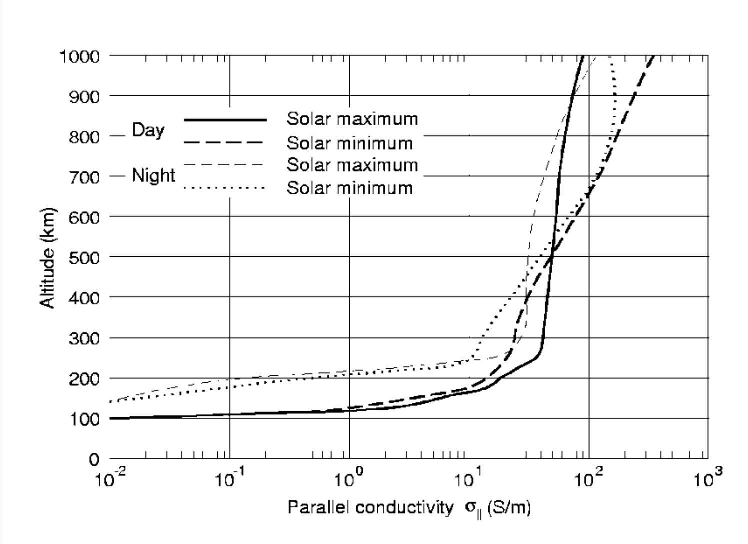
$$i_{//} = \sigma_{//} E_{//}$$

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

Ionospheric conductivities







Geomagnetic field

Approximated by a dipole close to Earth.

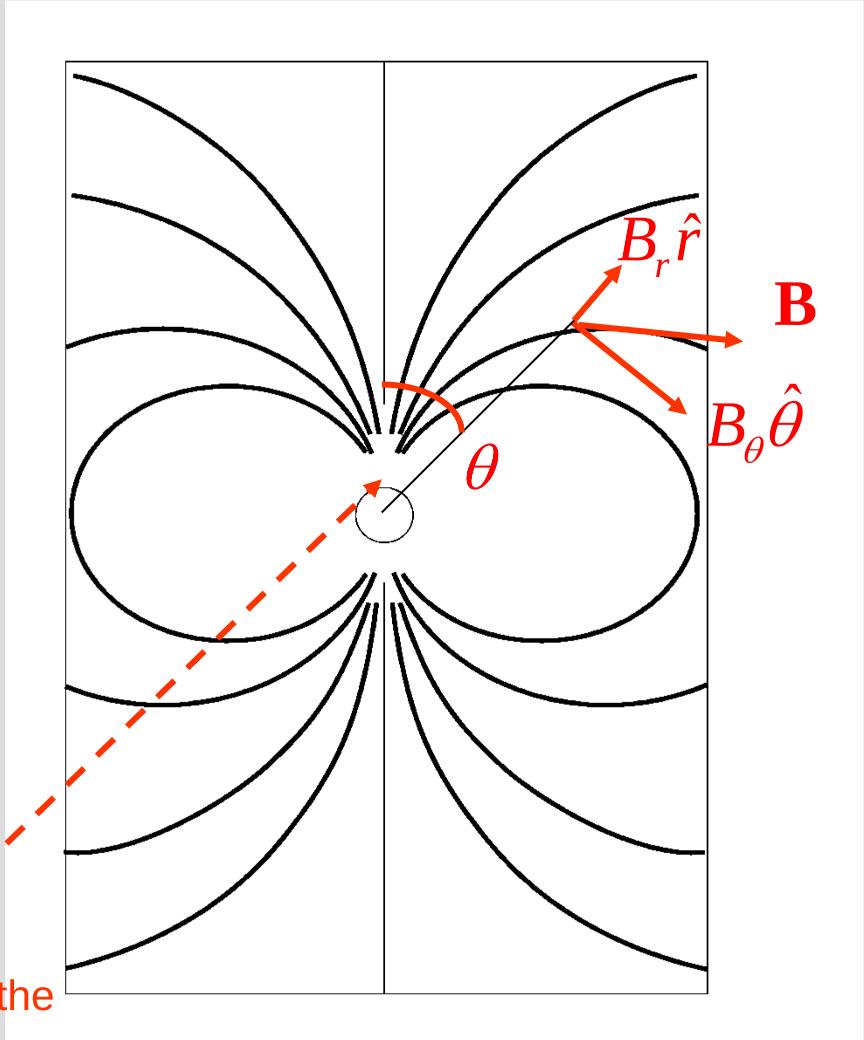
$$B_r = B_p \left(\frac{R_E}{r}\right)^3 \cos\theta$$

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

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

magnetic dipole moment

Magnetic field at the “north pole”



Geomagnetic field

Alternative formulation of dipole field

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

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

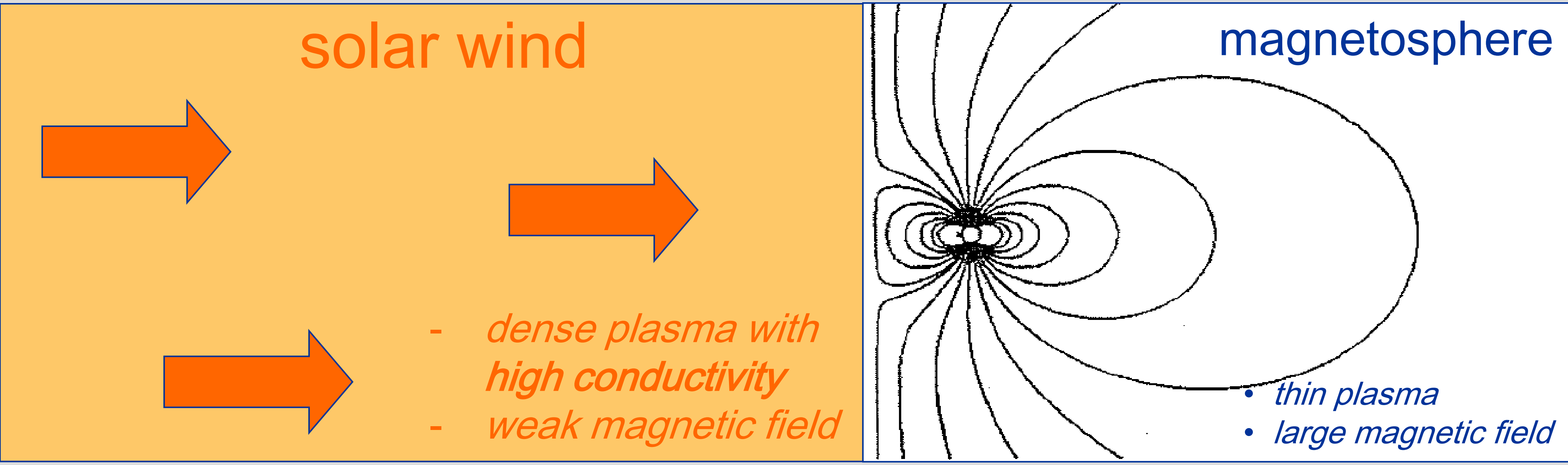
$$B_r = \frac{\mu_0 a}{2\pi} \frac{1}{r^3} \cos\theta$$

$$B_\theta = \frac{\mu_0 a}{2\pi} \cdot \frac{1}{2} \cdot \frac{1}{r^3} \sin\theta$$

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

magnetic dipole moment

Stand-off distance from pressure balance



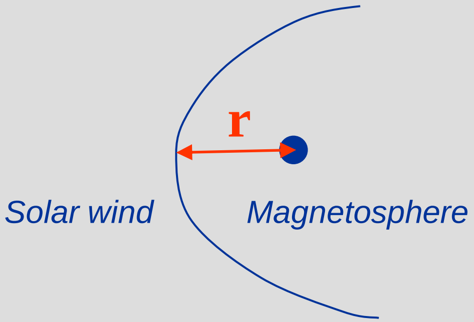
Dynamic pressure:

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

Magnetic pressure:

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

Magnetopause "stand-off distance"



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

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

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

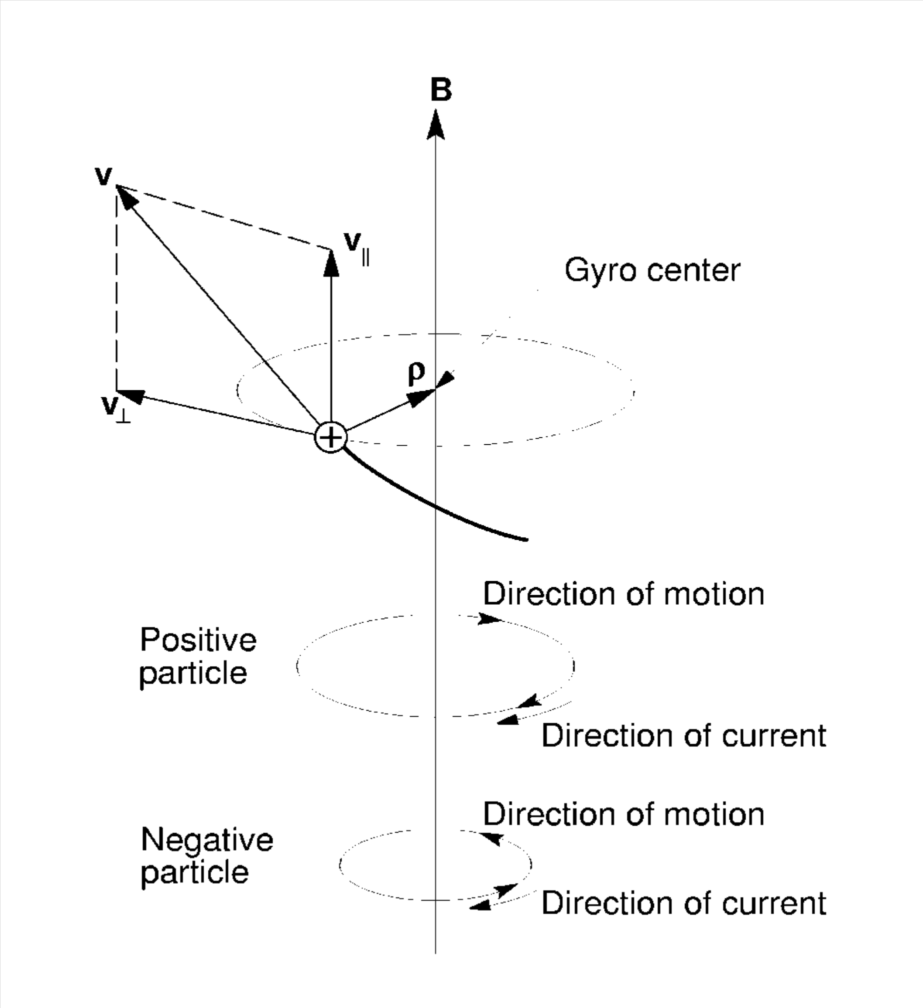
$$p_d = p_B \quad \Rightarrow \qquad \rho_{SW} v_{SW}^2 = \left[\frac{\mu_0 a}{4\pi} \frac{1}{r^3} \right]^2 / 2\mu_0 \quad \Rightarrow$$

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

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

r = 7 R_e (1 R_e = 6378 km)

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:

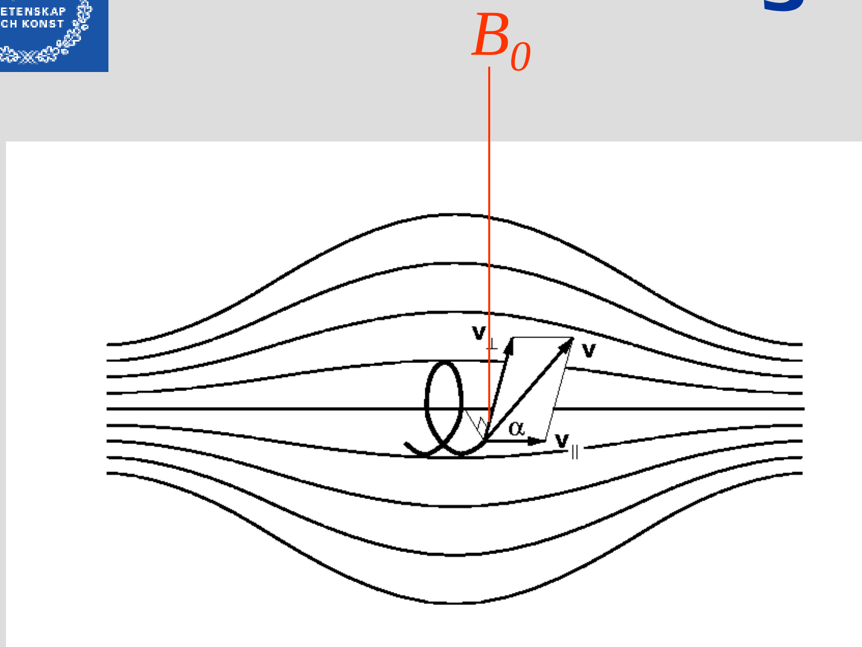
An **adiabatic invariant** is a property of a physical system which stays constant when changes are made slowly.

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) ➡

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

particle turns when α = 90° ➡

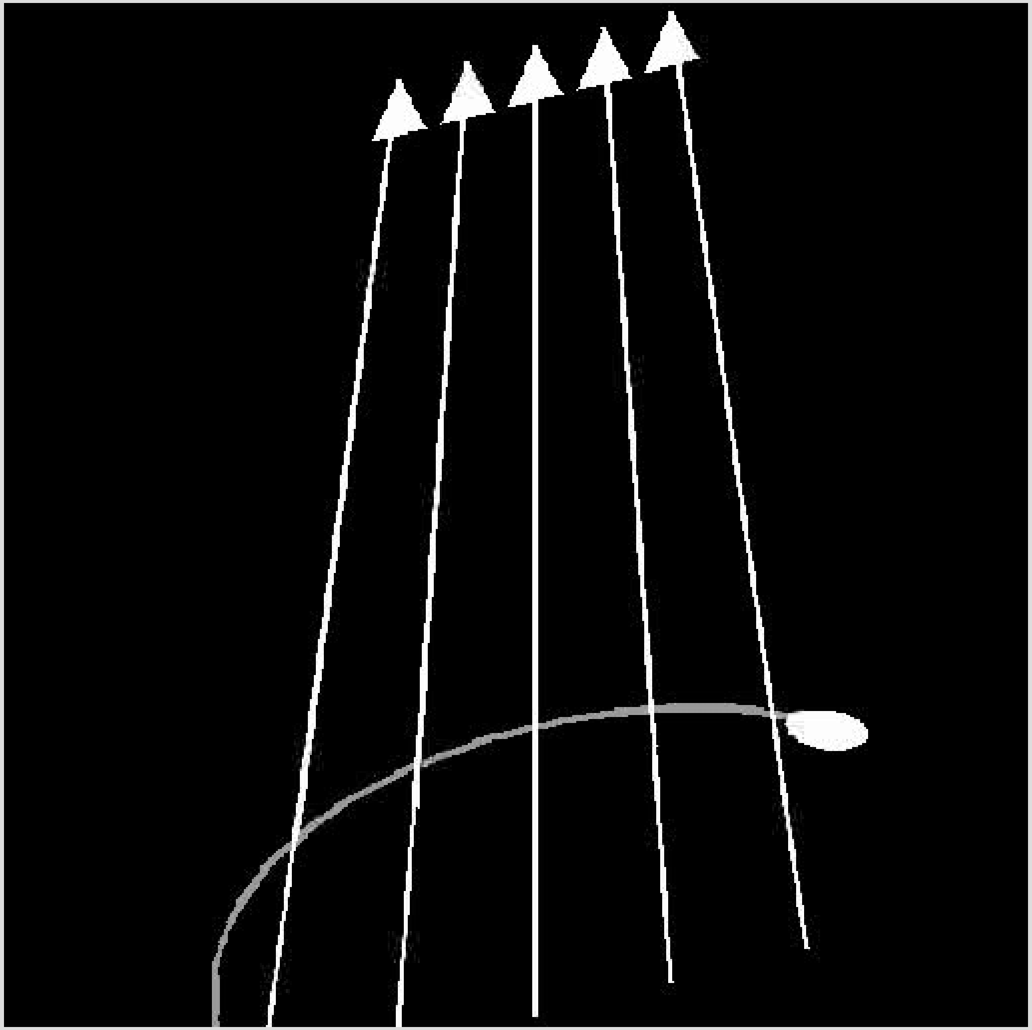
$$\frac{B_{turn}}{\sin^2 90^\circ} = \frac{B_0}{\sin^2 \alpha}$$ ➡

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

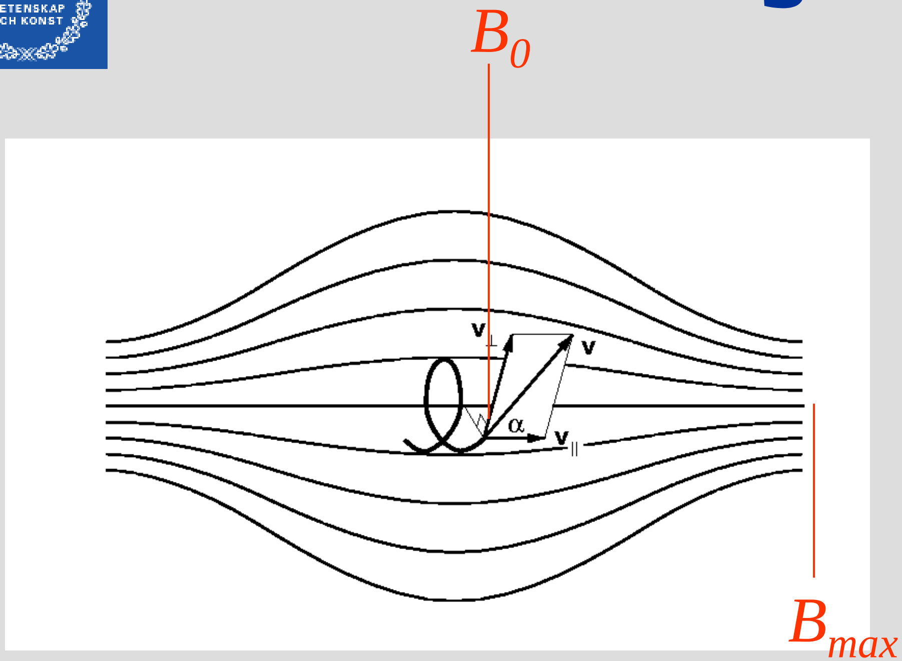
The magnetic moment μ is an ***adiabatic invariant***.

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

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 α can only be turned around if

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

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

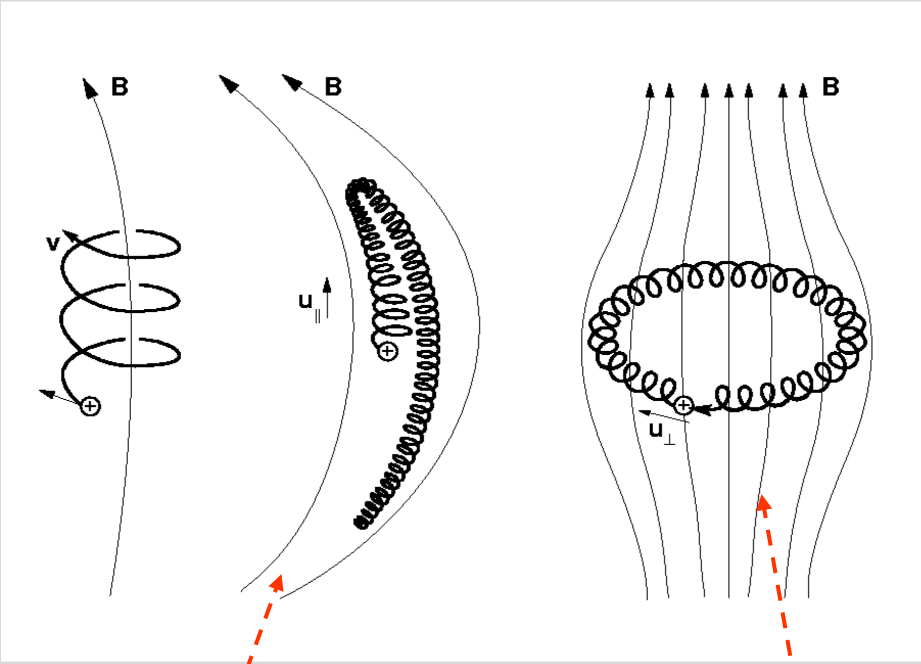
Particles in ***loss cone*** : $\alpha < \alpha_{lc}$

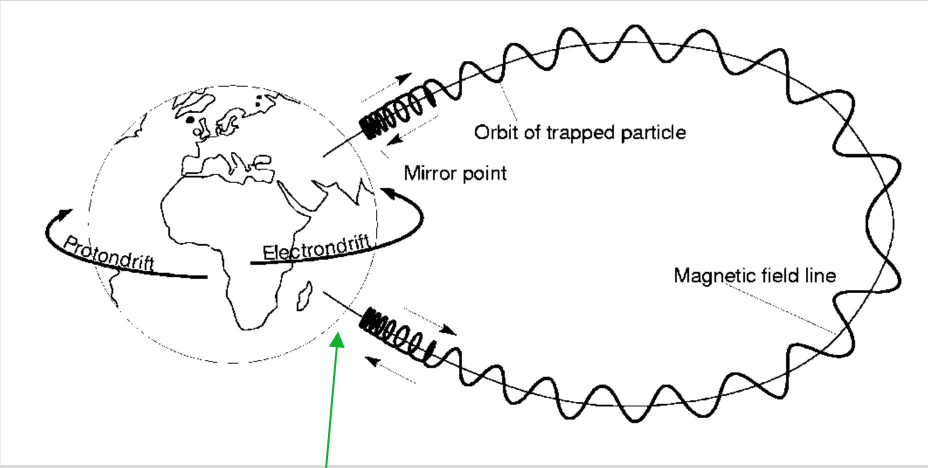
The magnetic moment μ is an ***adiabatic invariant***.

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

Particle motion in geomagnetic field

gyration | longitudinal oscillation | azimuthal drift





Magnetic mirror

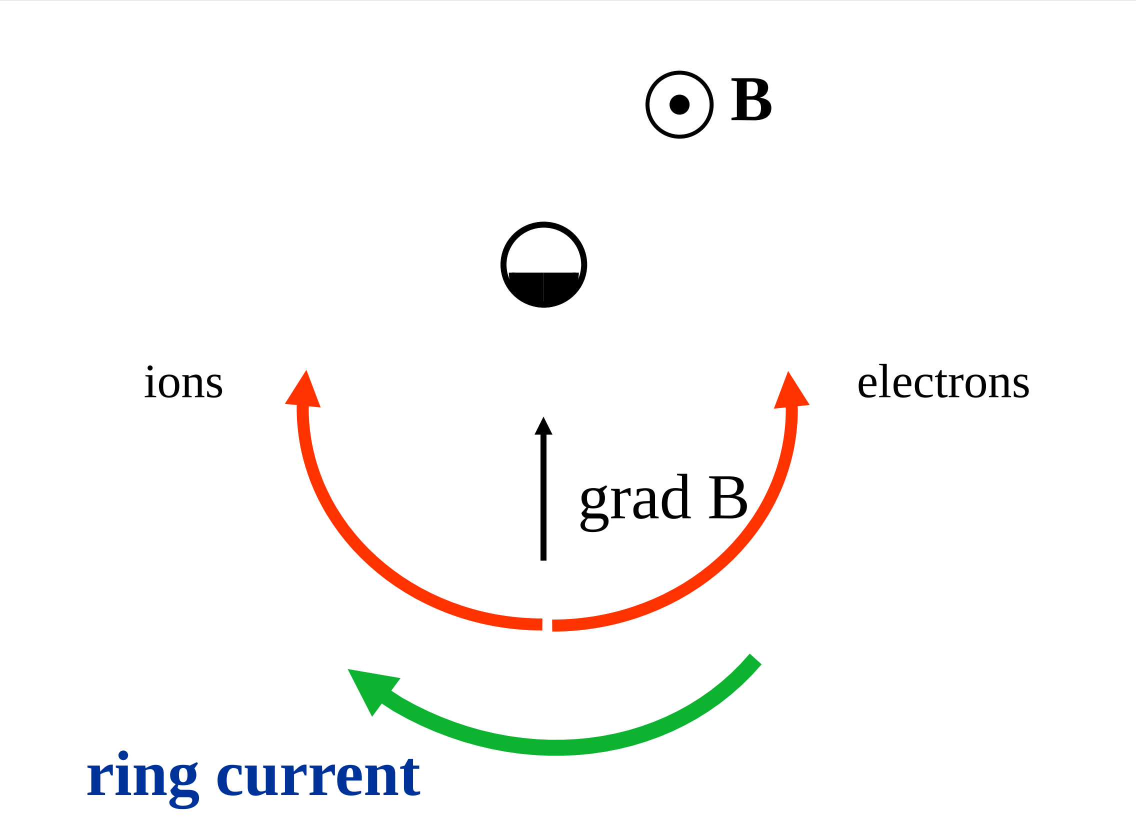
grad B drift

Particles in the loss cone create the aurora!

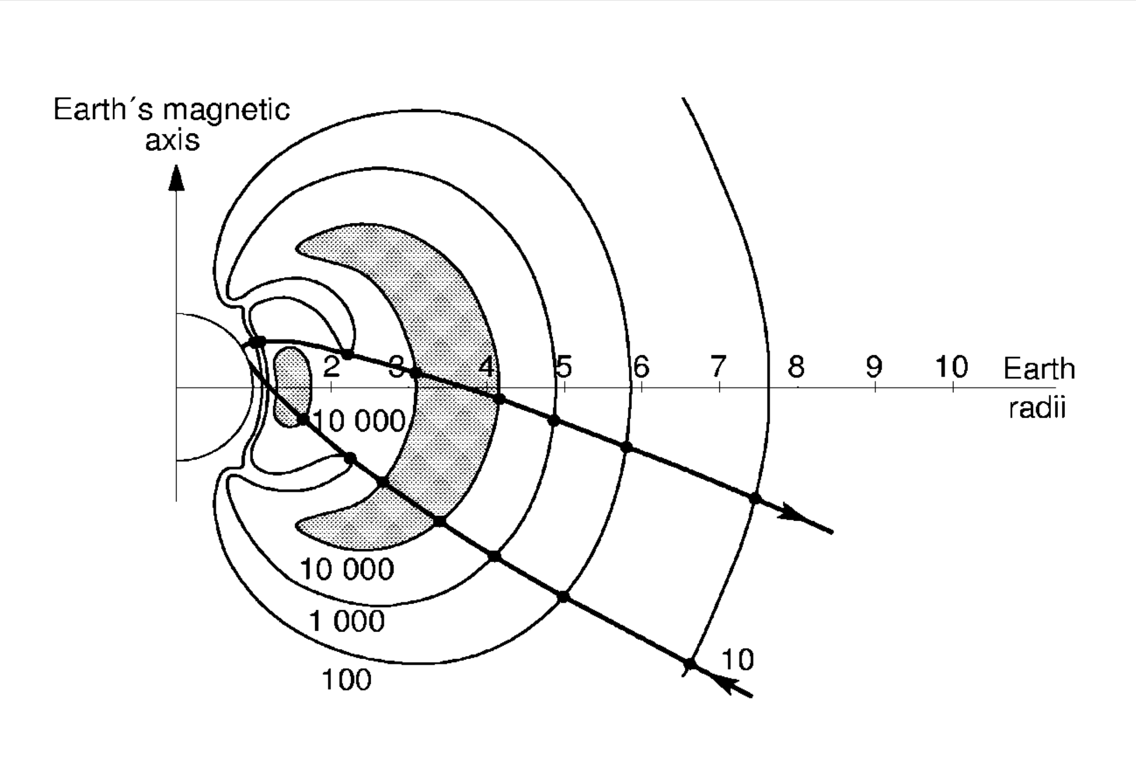
Ring current and particle motion

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

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



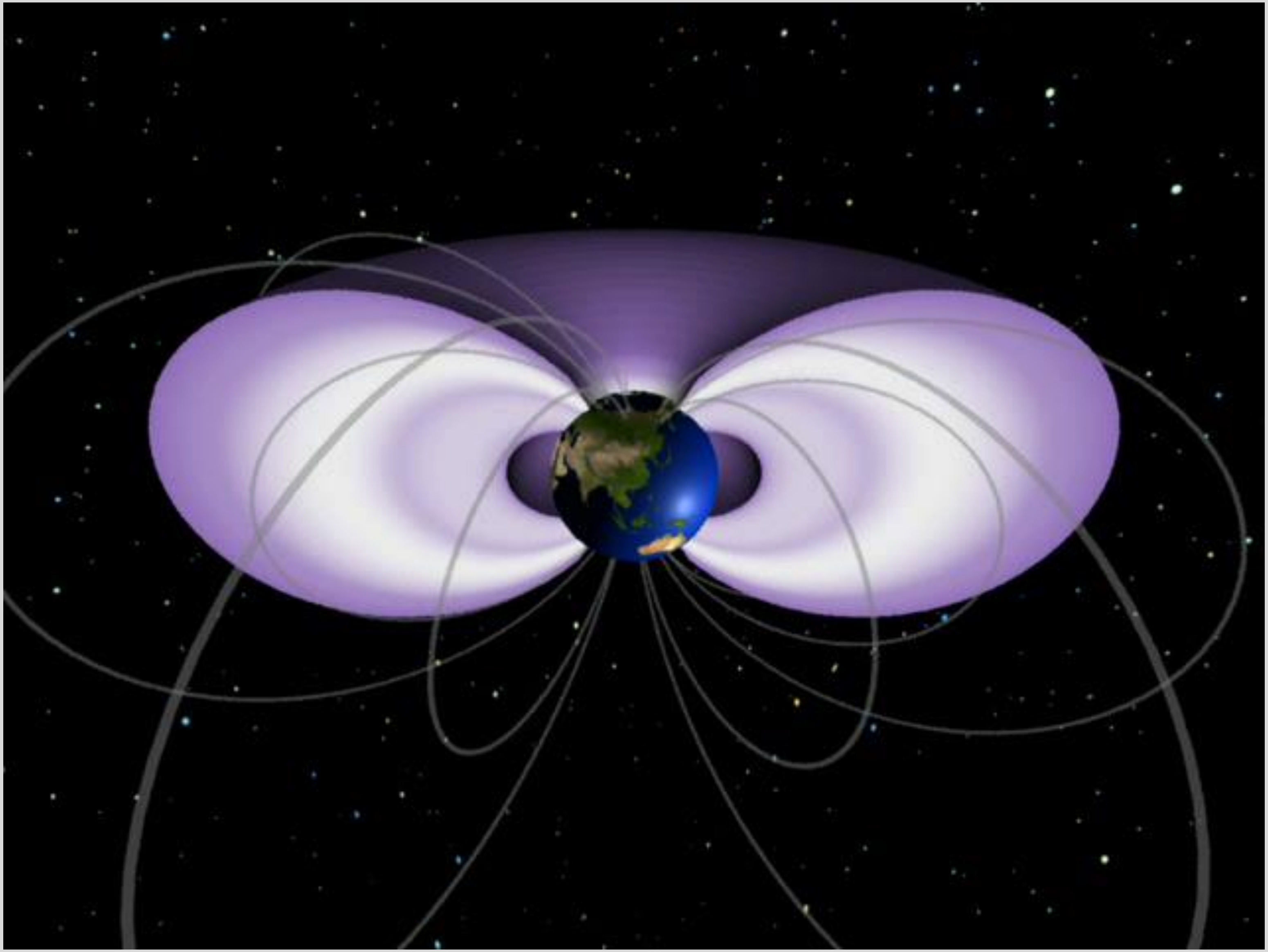
Radiation belts



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

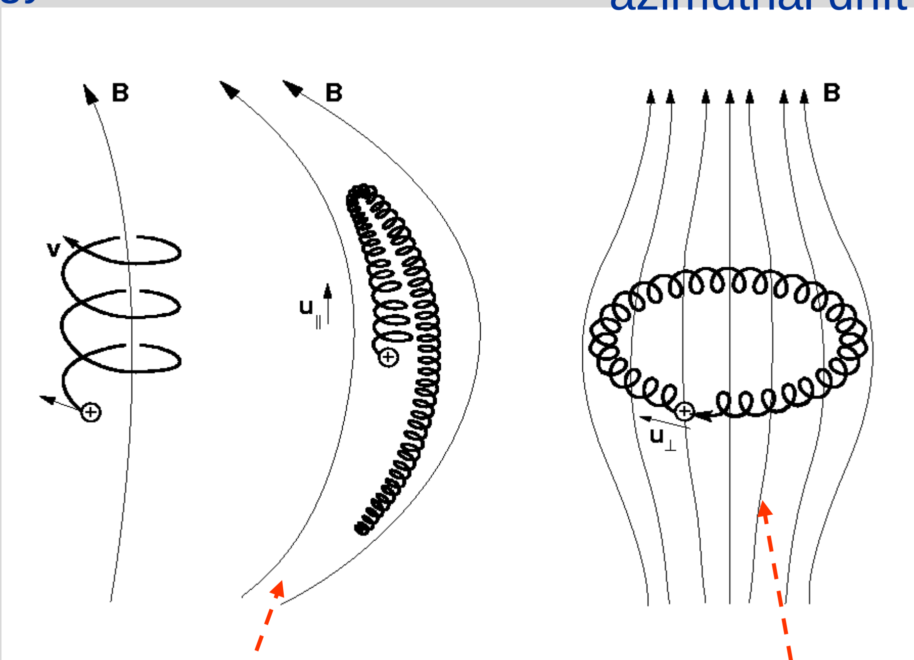


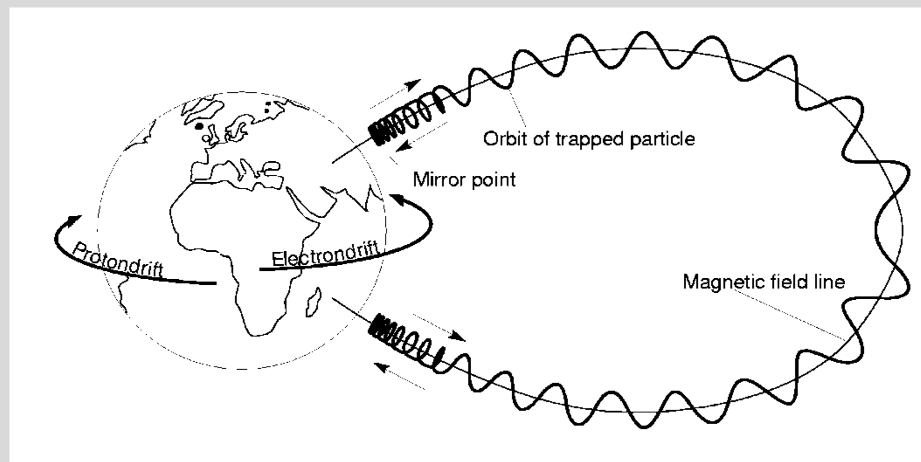
Particle motion in geomagnetic field

longitudinal oscillation

gyration

azimuthal drift





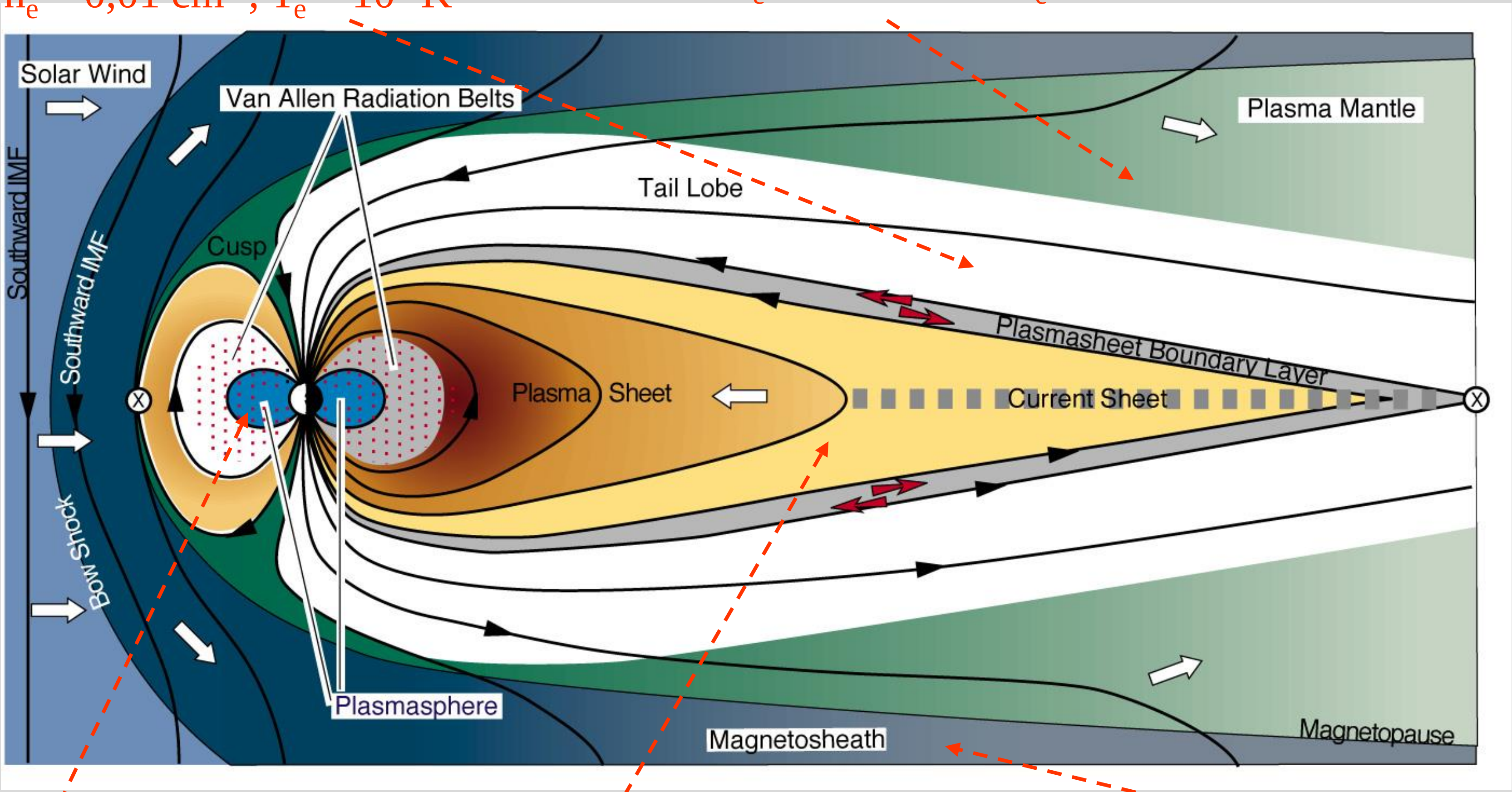
Magnetic mirror

grad B drift

Magnetospheric structure

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

plasma mantle
n_e ~ 0,1-1 cm^{-3}, T_e ~ 10^6 K

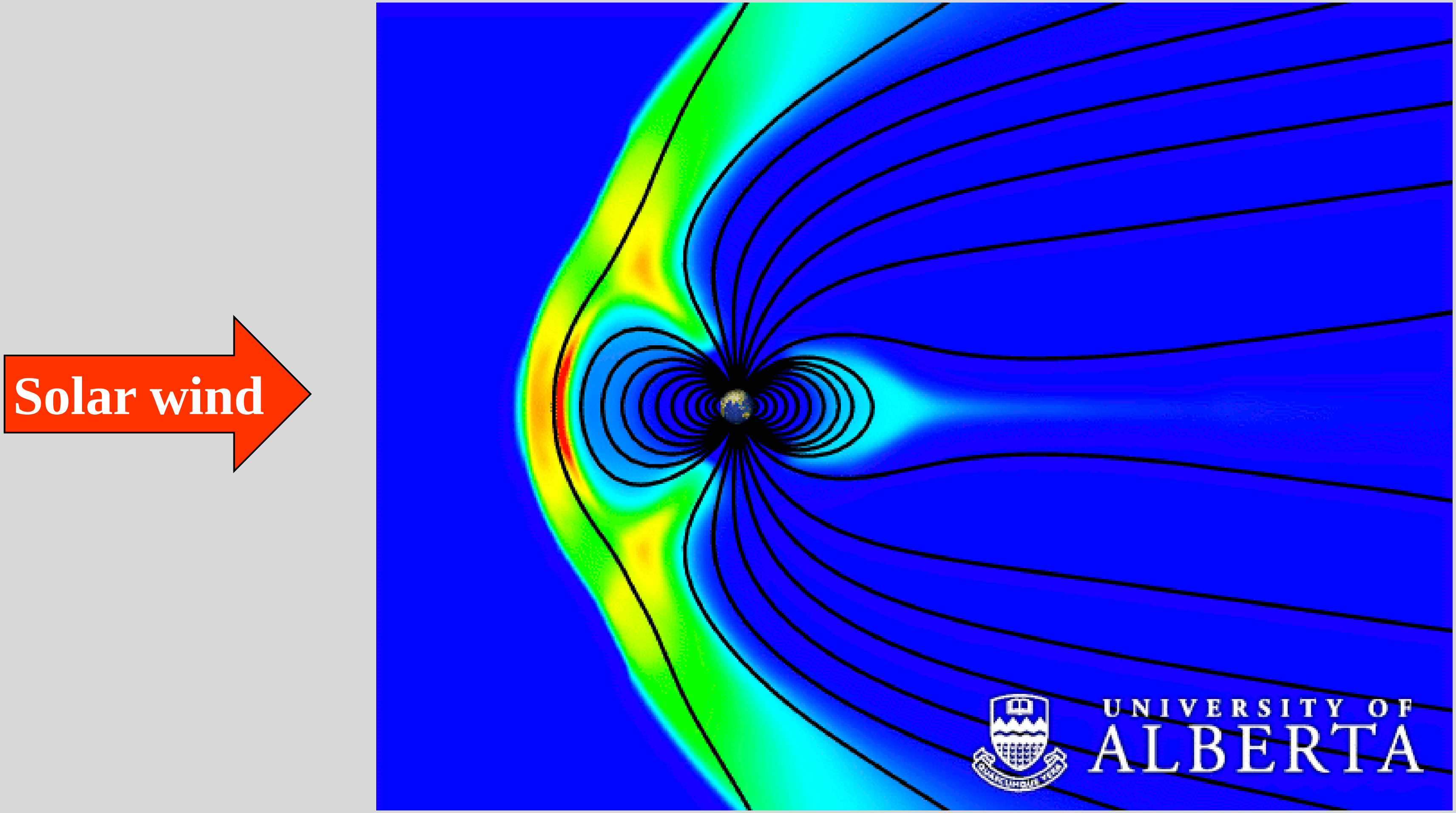


plasmasphere:
n_e ~ 10-100 cm^{-3}, T_e ~ 1000 K

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

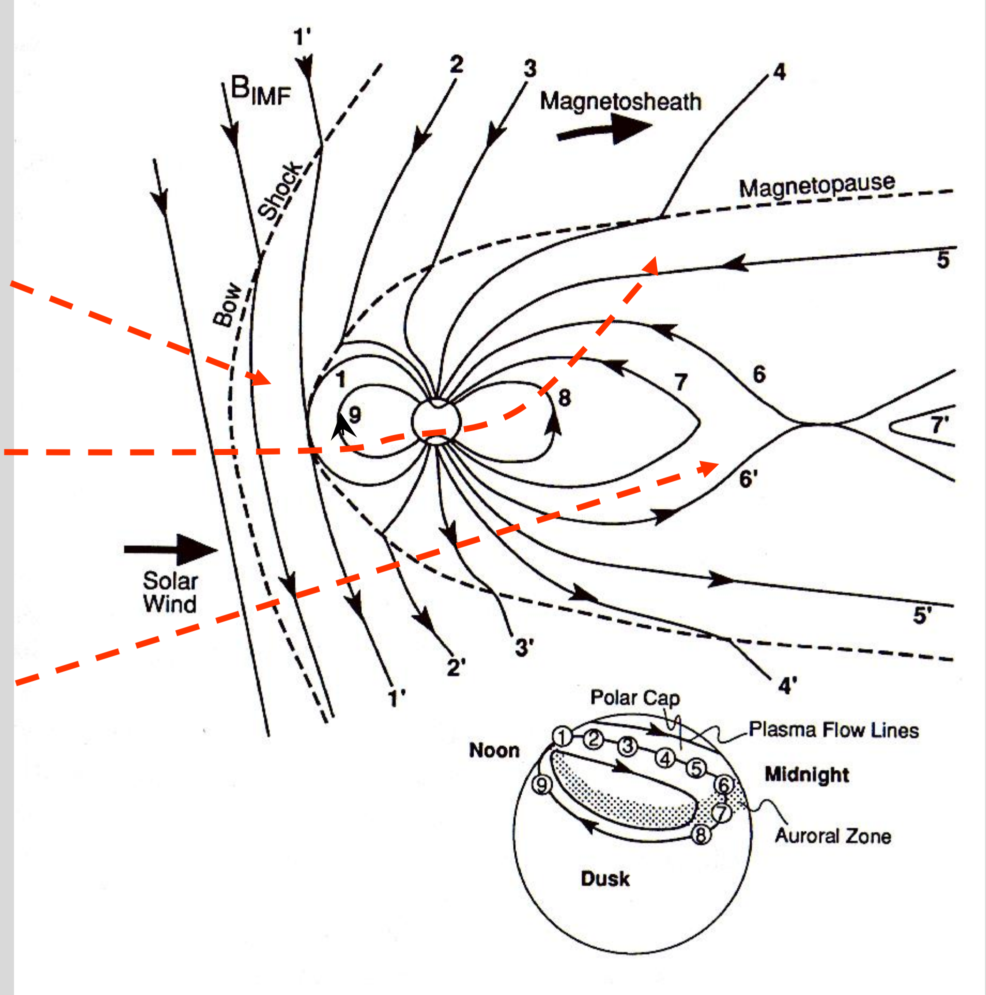
magnetosheath:
n_e ~ 5 cm^{-3}, T_e ~ 10^6 K

Reconnection and plasma convection

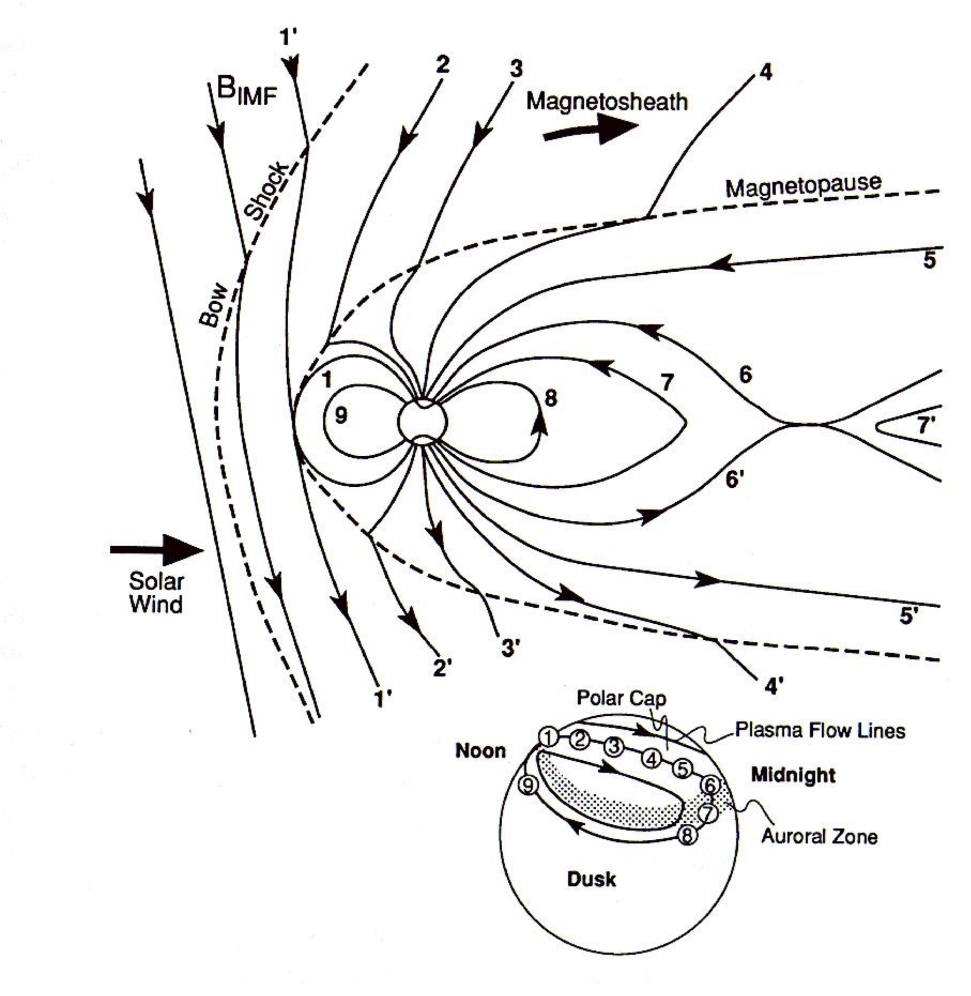


Reconnection och plasma convection

- 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.

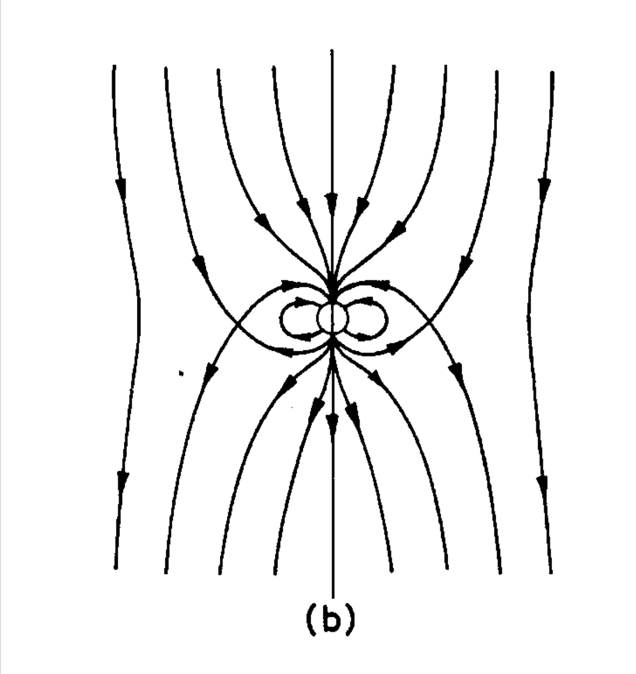


What happens if IMF is northward instead?

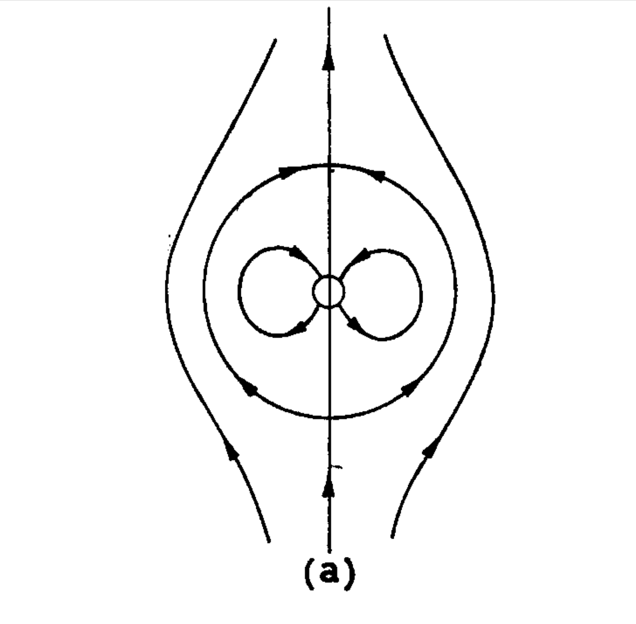


Magnetospheric dynamics

open magnetosphere



closed magnetosphere



southward

Interplanetary magnetic field (IMF)

northward

What do the magnetospheres of the other planets look like?

Planetary magnetospheres

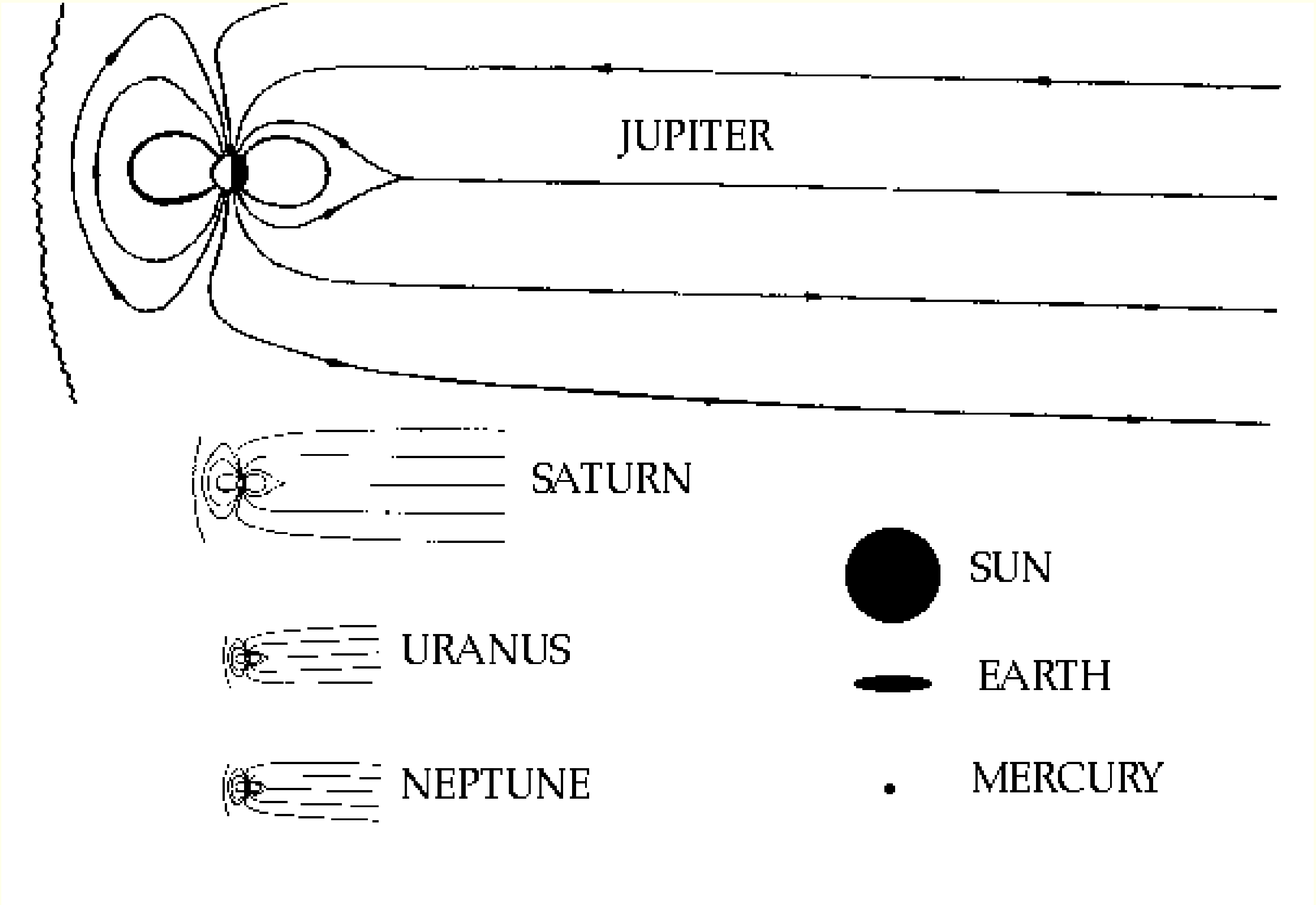
	Radius Earth radii	Spin period (days)	Equatorial field strength (μT)	Magnetic axis direction relative to spin axis	Polarity relative to Earth´s	Typical magneto-pause distance (planetary radii)
Mercury	0.38	58.6	0.35	10^o	Same	1.1
Venus	0.95	243	< 0.03	-	-	1.1
Earth	1.0	1	31	11.5^o	Same	10
Mars	0.53	1.02	0.065	-	Opposite	?
Jupiter	11.18	0.41	410	10^o	Opposite	60-100
Saturn	9.42	0.44	40	$<1^o$	Opposite	20-25
Uranus	3.84	0.72	23	60^o	Opposite	18-25
Neptune	3.93	0.74	20-150*)	47^o	Opposite	26**)

*) The magnetic field differs greatly from a dipole field. The numbers represent maximum and minimum strength at the planetary surface

**) Based on single passage

Very weak magnetic fields

Relative size of the magnetospheres



Comparative magnetospheres
In situ observations

Space probe	*Celestial body*	*Observations*
Mariner 10	Mercury	*1974 – 1975*
*Messenger **	Mercury	*2008 – 2015*
Pioneer 10,11	Jupiter, Saturn	*1973 – 1979*
Voyager 1,2	Jupiter, Saturn, Uranus, Neptune	*1977 – 1989*
Ulysses	Jupiter	*1992*
*Galileo**	Jupiter	*1995 – 2003*
*Cassini**	Jupiter, Saturn	*2004 –*
New Horizons	Jupiter	*2007*
Rosetta	Churymov-Gerasimenko	*2014 - 2016*

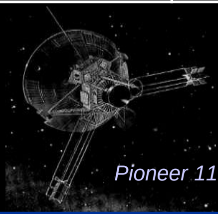
** Orbiters*


Mariner 10


Ulysses

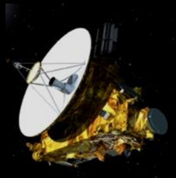

Rosetta

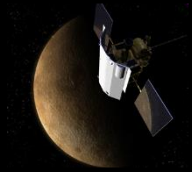

Pioneer 10


Pioneer 11


Voyager 1 and 2


Galileo


New Horizons


Messenger


Cassini

Mercury

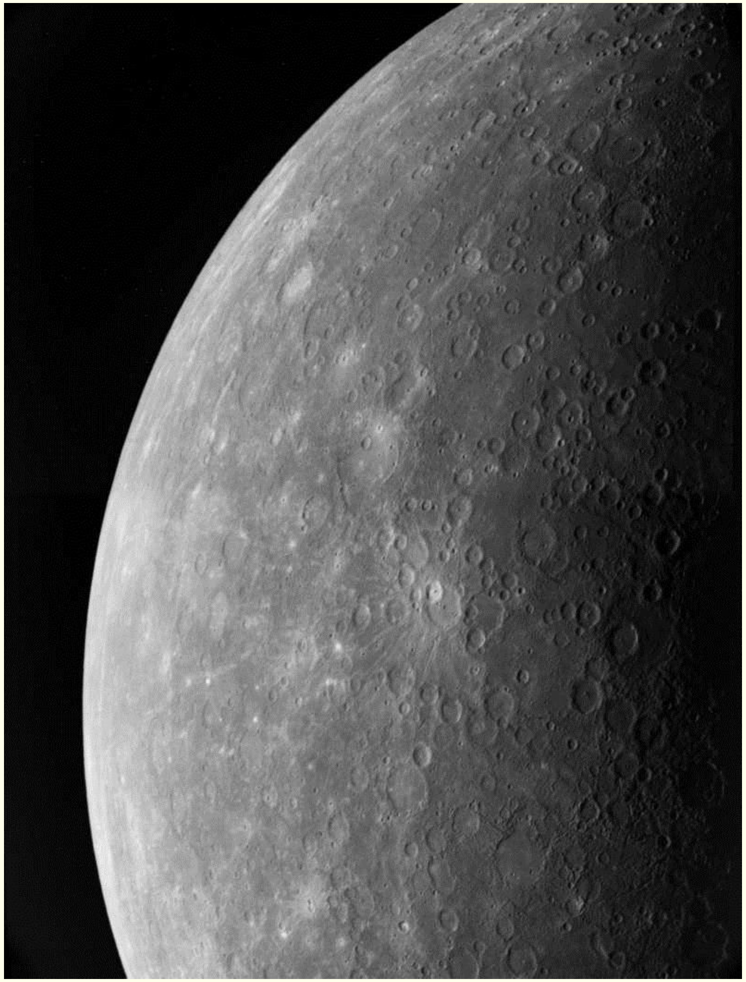
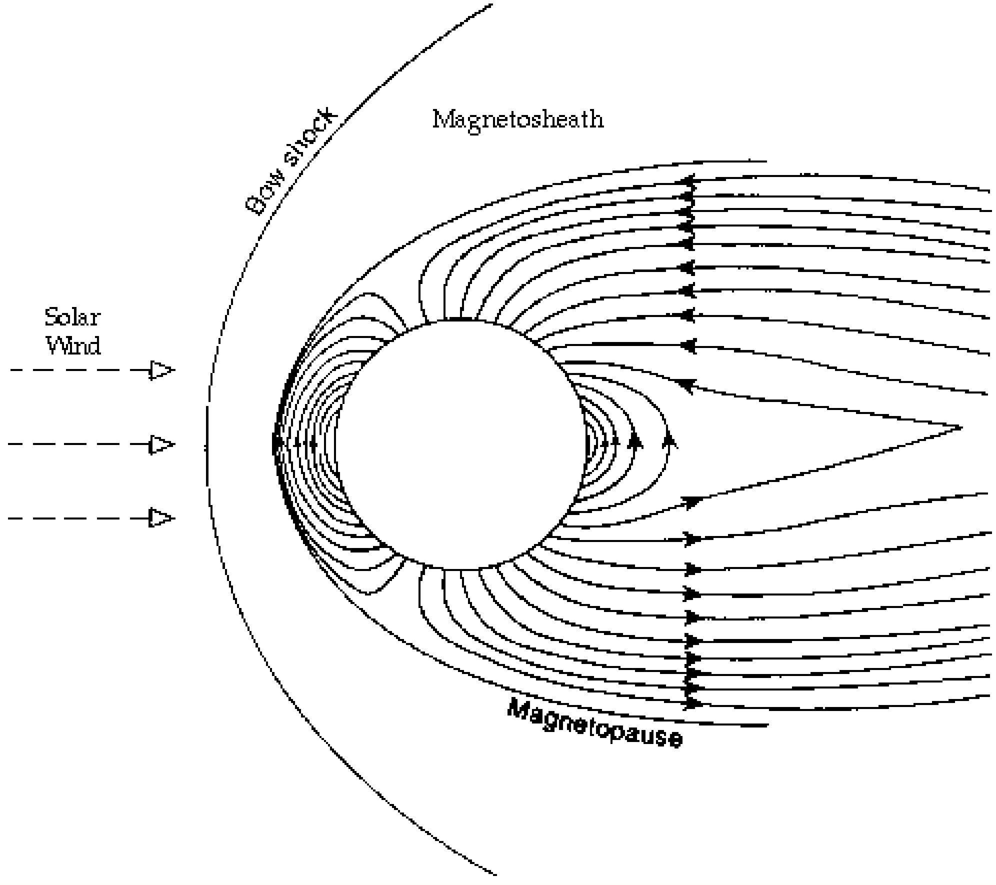


Photo from Mariner 10

- $r_M = 0{,}38\ r_E$
- $m_M = 0{,}06\ m_E$
- distance from sun: 0,39 AU
- no or extremely thin atmosphere

Mercury's magnetosphere



- rather large magnetic field
- the high solar wind density close to the sun makes the magneto-sphere very small
- no ionosphere

Venus

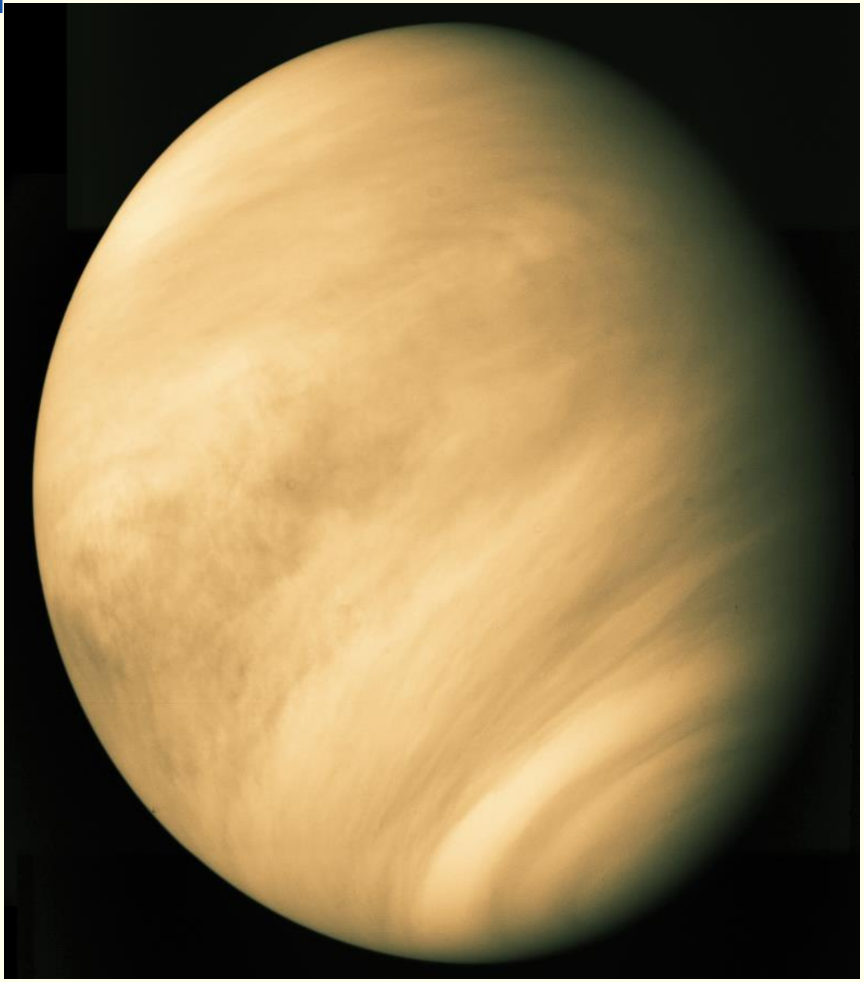
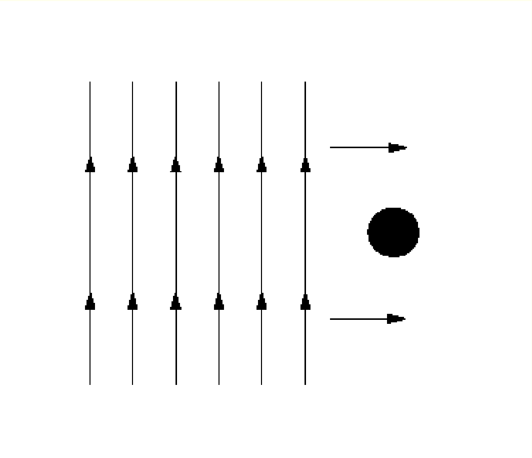


Photo from Galileo

- $r_V = 0{,}95\ r_E$
- $m_V = 0{,}82\ m_E$
- distance from sun : 0,72 AU
- very dense atmosphere
  - ~ 90 atm
  - 96% CO_2
- very weak magnetic field

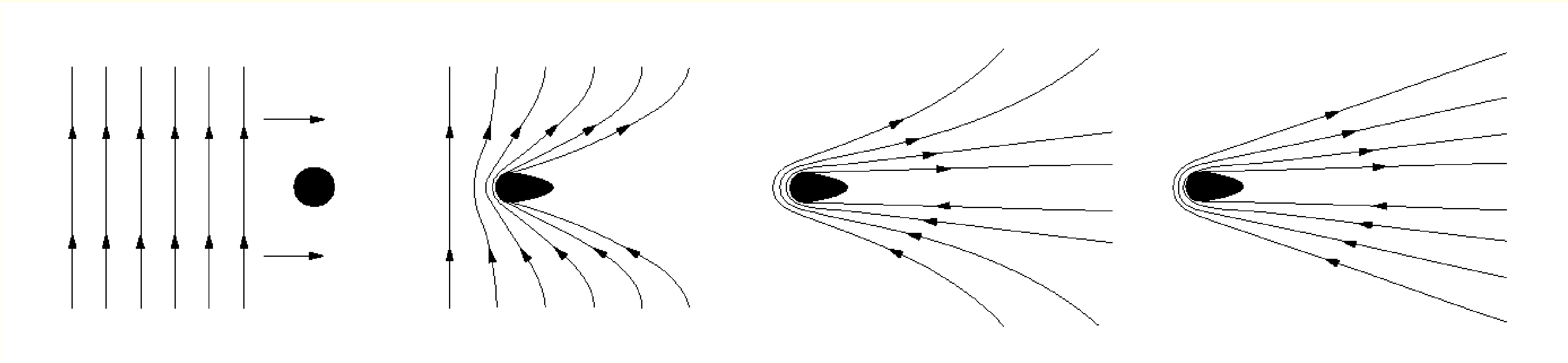
Comets, induced magnetotail



- The ***coma*** of the comet is ionized when the comet gets close to sun

What will happen when the interplanetary magnetic field (which is frozen into the solar wind) hits the coma?

Comets, induced magnetotail



- The ***coma*** of the comet is ionized when the comet gets close to sun
- This plasma stops the field lines from passing the comet, due to the frozen-in magnetic field
- Venus and Mars have similar induced, weak ”magnetospheres”

Mars

Photo from Hubble Space Telescope

- $r_M = 0{,}53\ r_E$
- $m_M = 0{,}11\ m_E$
- distance from sun : 1,52 AU
- very thin atmosphere
  - ~ 0.01 atm.
  - 95% CO_2
- very weak magnetic field

Jupiter

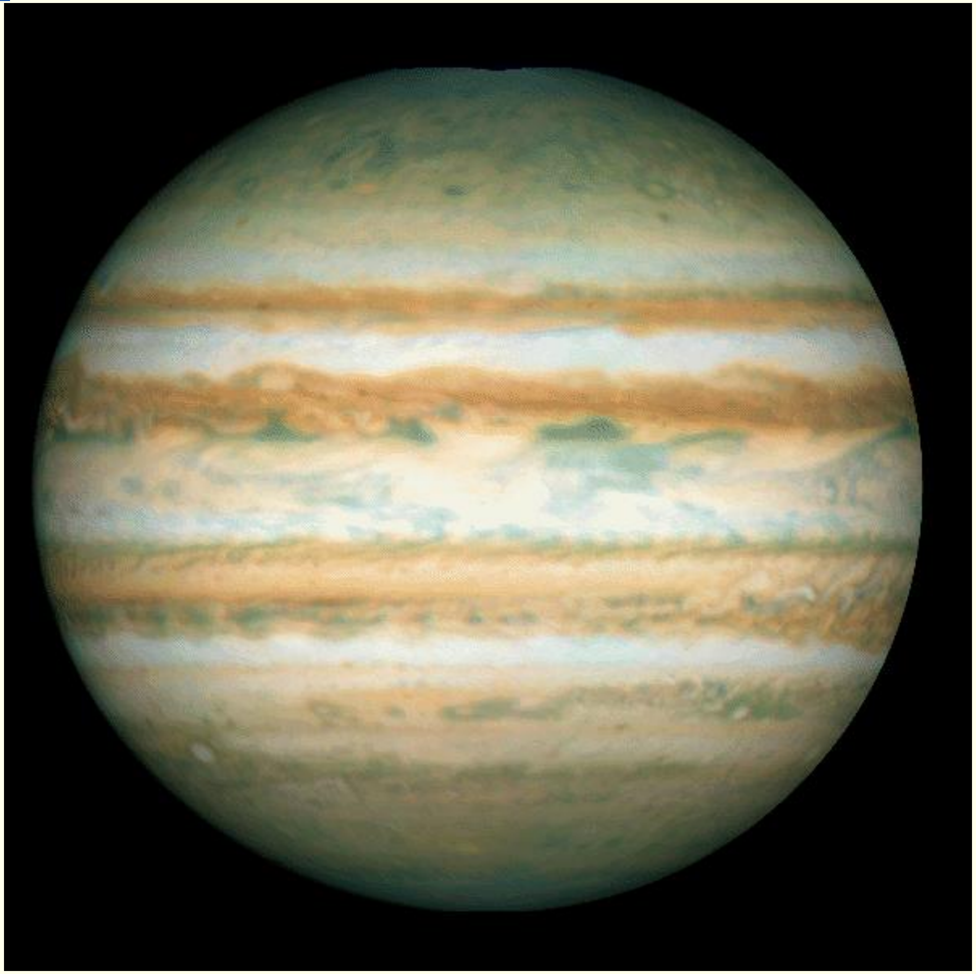
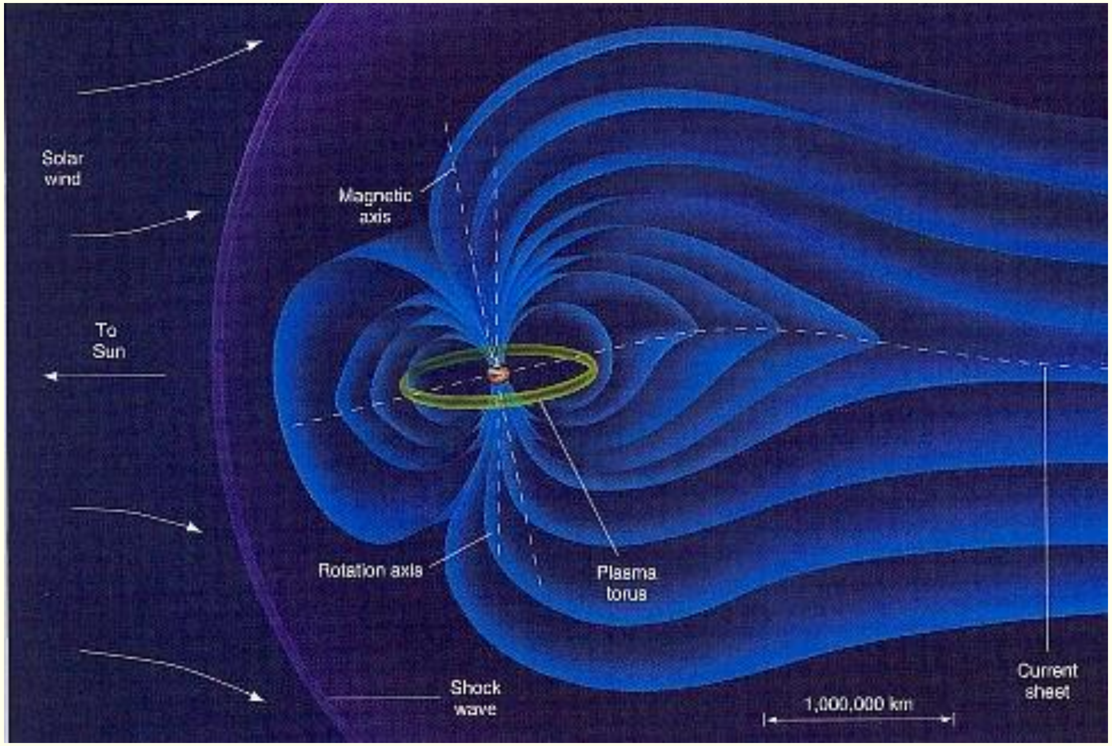


Photo from Hubble Space Telescope

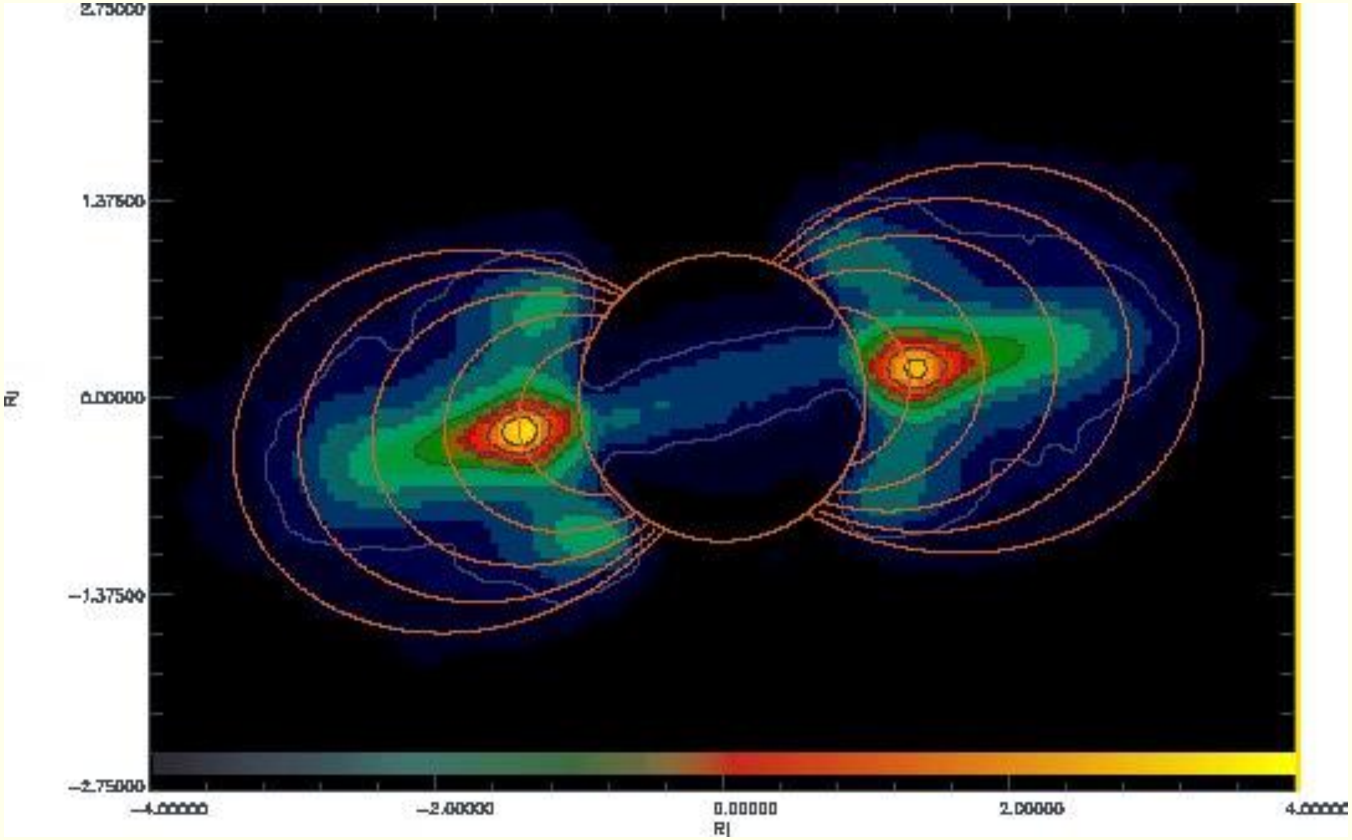
- r_J = 11,2 r_E
- m_J = 318 m_E
- distance from sun: 5,20 AU
- gas giant with very dense atmosphere containing hydrogen, helium, ammonium, methane, etc.
- ~ 60 moons (+ weak ring system)

Jupiter's magnetosphere



- high plasma density, Io is an important source
- plasma pressure thus becomes an important factor for balancing the solar wind pressure
- the plasma co-rotates with Jupiter, which gives the magnetosphere a flattened look

Syncrotron radiation from Jupiter's radiation belts

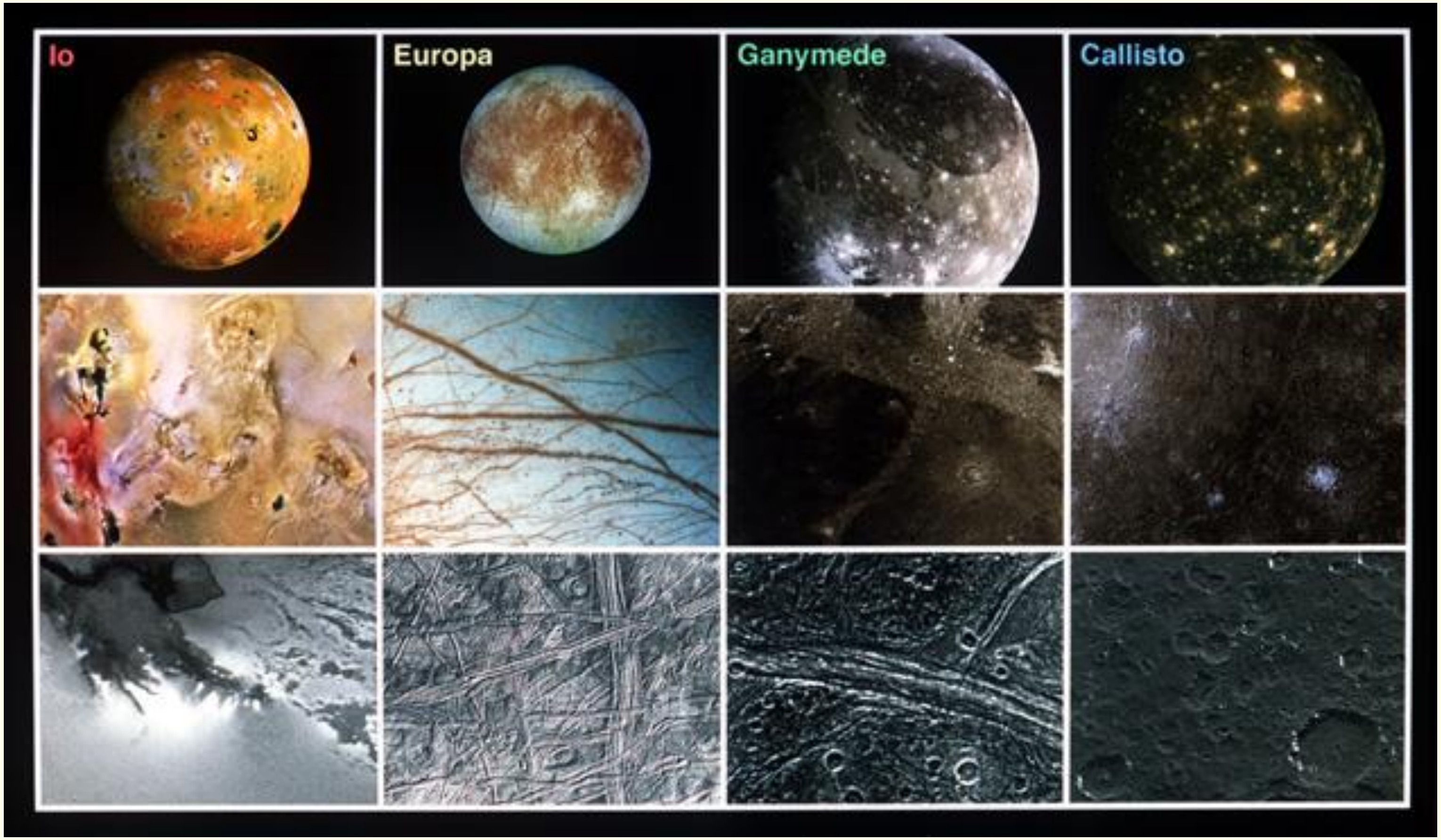


- Gyrating electrons emit "syncrotron radiation" with frequencies ~ $f_{ce} = eB/(2\pi m_e)$
- The emitted power is proportional to the electron temperature:

  $P = CT_e$

- In this way you can get a picture of the radiation belts

Galilean satellites



Volcanic activity, source for plasma.

Oceans under the ice?

Has its own magnetosphere the size of Mercury's

Weak magnetic field

Saturn

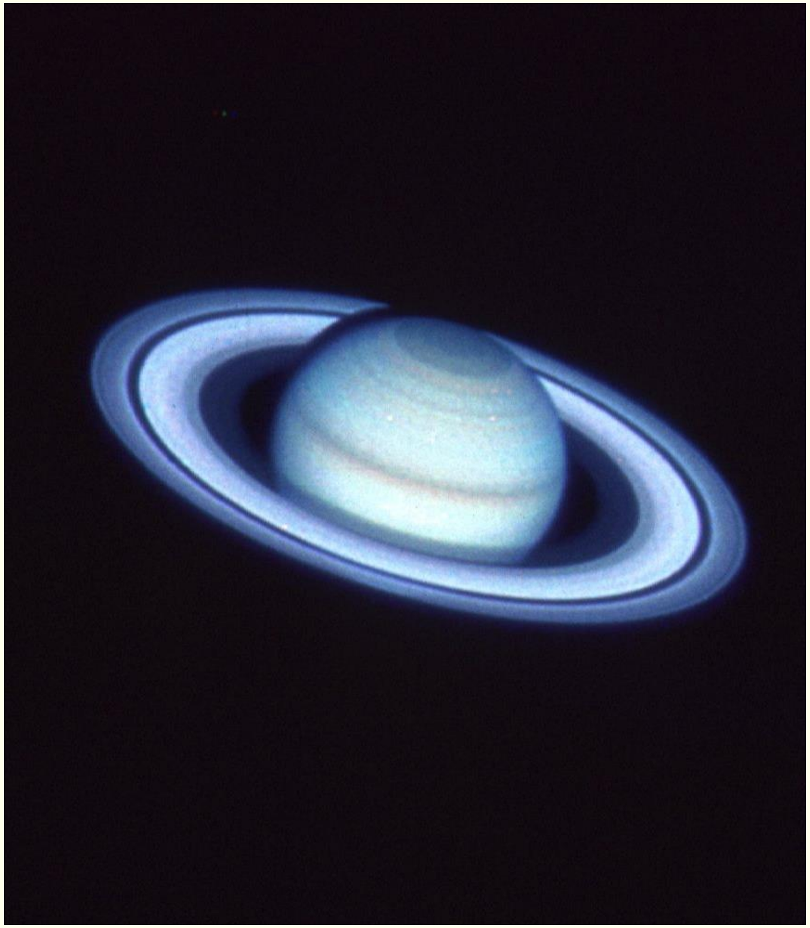
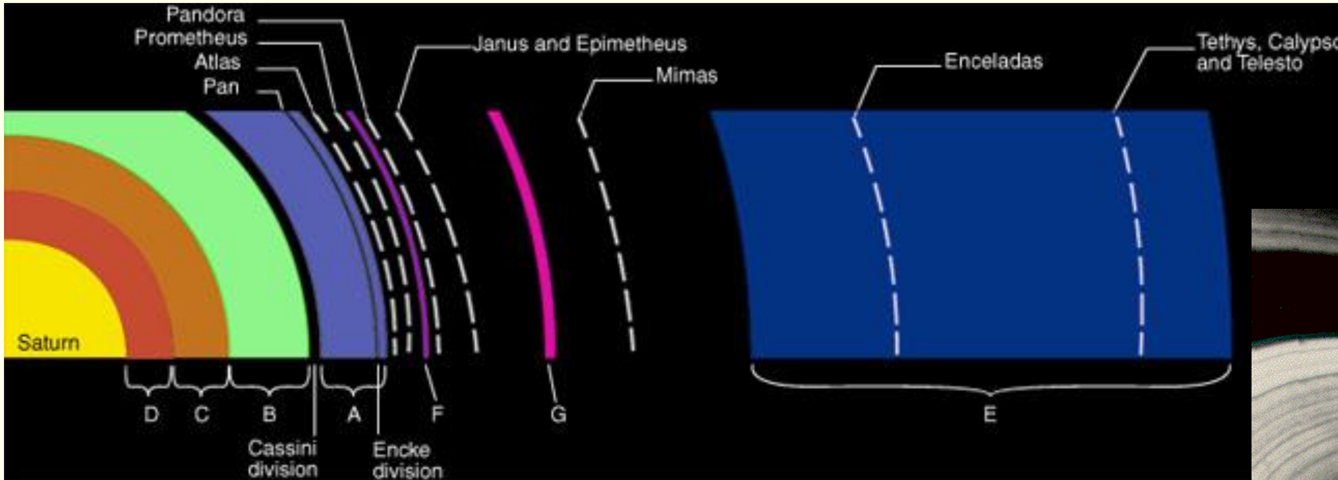
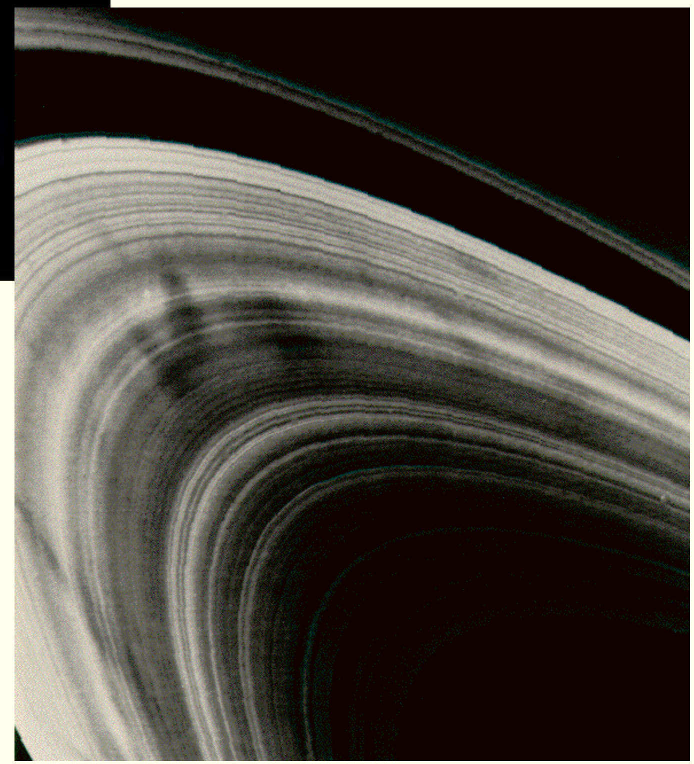


Photo from Hubble Space Telescope

- $r_s = 9{,}42\ r_E$
- $m_S = 95\ m_E$
- distance from sun: 9.53 AU
- gas giant with very dense atmosphere containing sulphur, hydrogen, helium, ammonium, methane, etc.
- ~ 31 moons + ring system

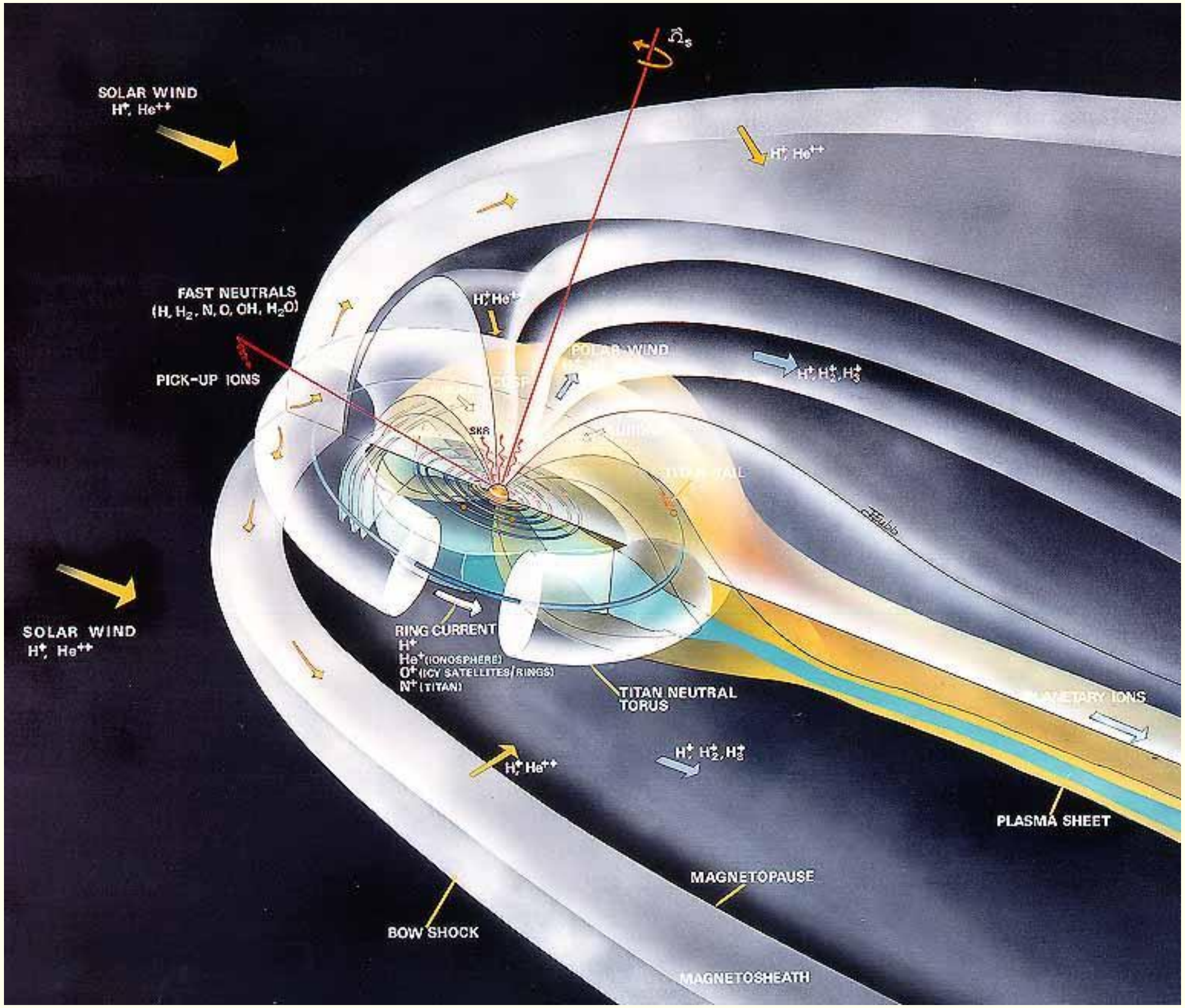
Saturn's rings



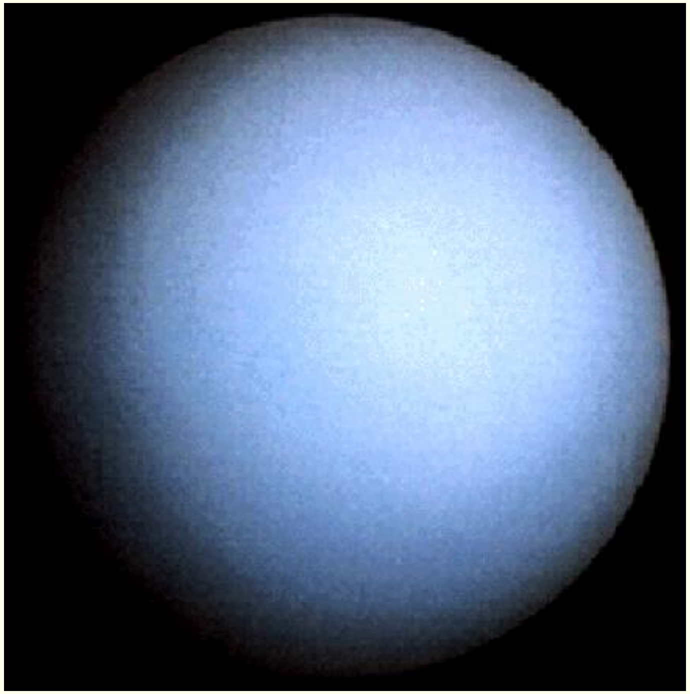


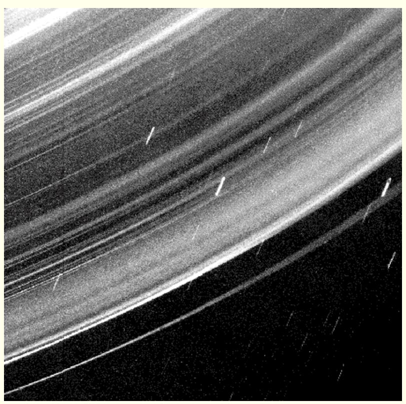
- ring systemet is made up of ice and mineral particles from ~ 1 cm to ~ 1 km
- rings are only 1.5 km thick

Saturn's magnetosphere



- ring systemet is both source and sink for plasma and limits the size of the plasmasphere
- plasma pressure important for balancing solar wind pressure, just as for Jupiter
- Intense radiation belt with 50 MeV protons

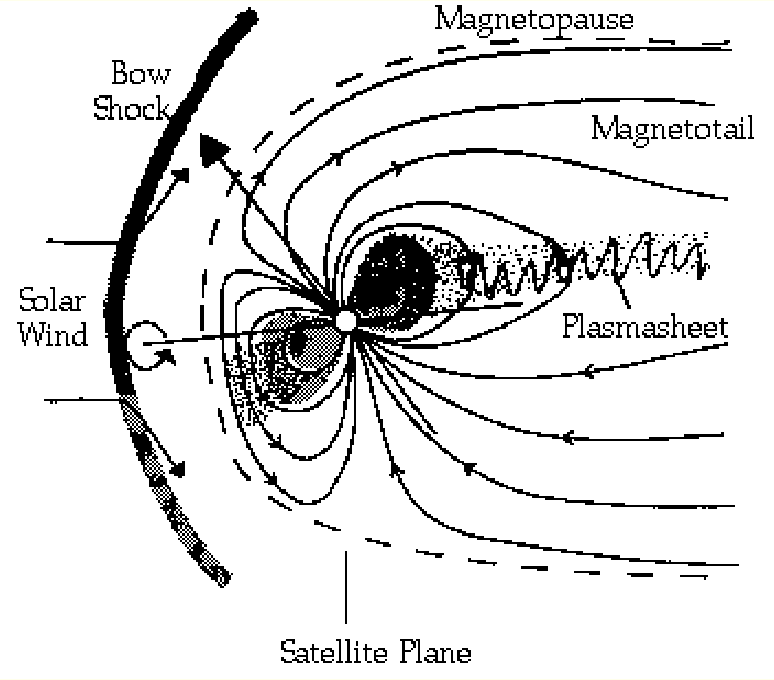


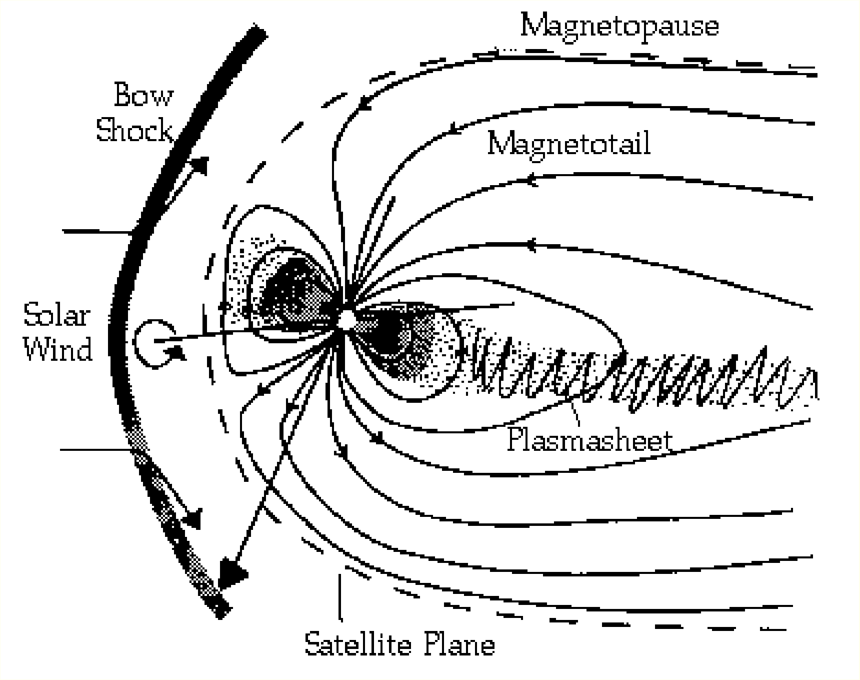


Uranus

- $r_U = 3{,}84\ r_E$
- $m_U = 14{,}5\ m_E$
- distance from sun: 19,2 AU
- gas giant with very dense atmosphere containing mainly methane
- 20 moons + ring system

Uranus





- Uranus' rotational axis almost in ecliptic plane
- magnetic field axis makes an angle of around 60° with rotational axis
- this gives enourmous daily variations of the structure of the magnetosphere

Neptune

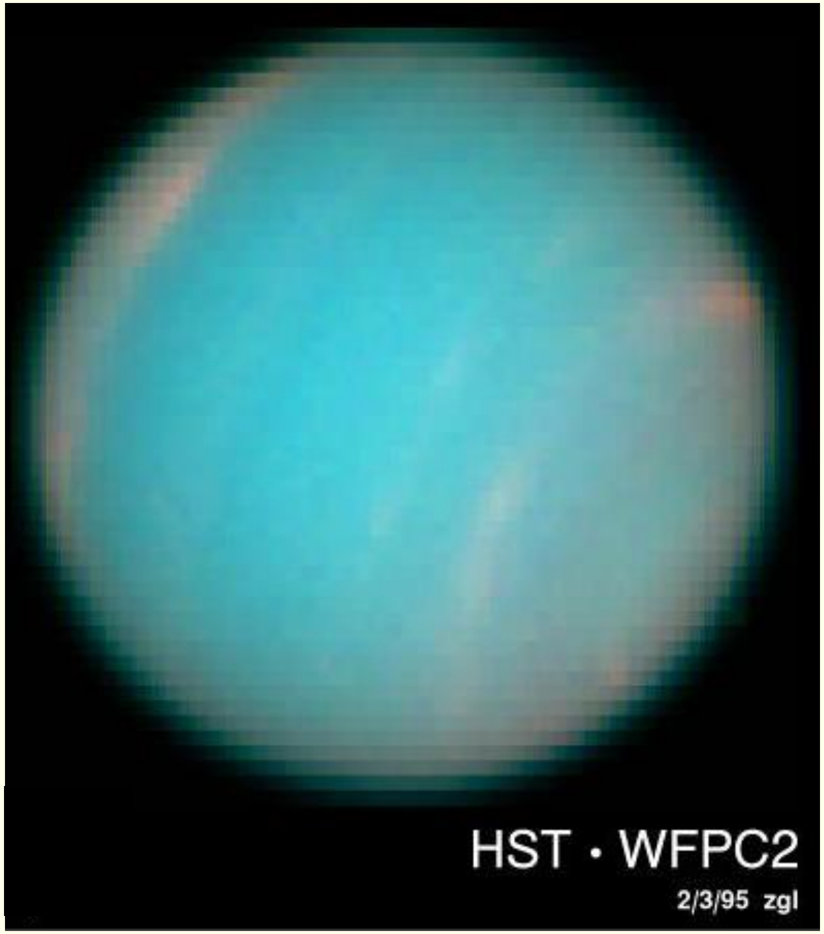
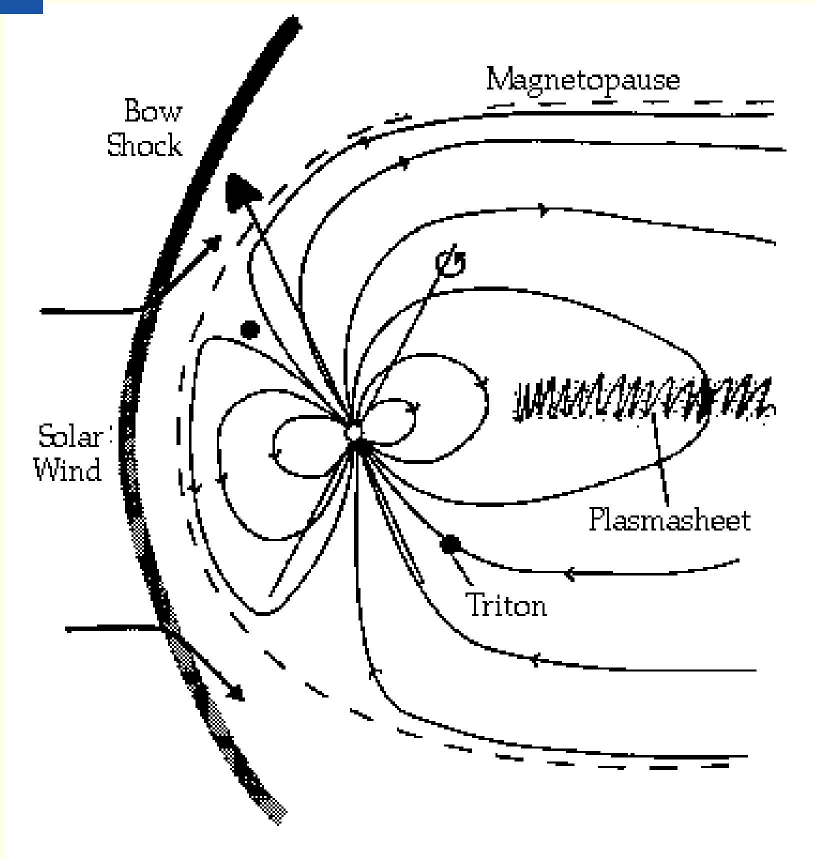
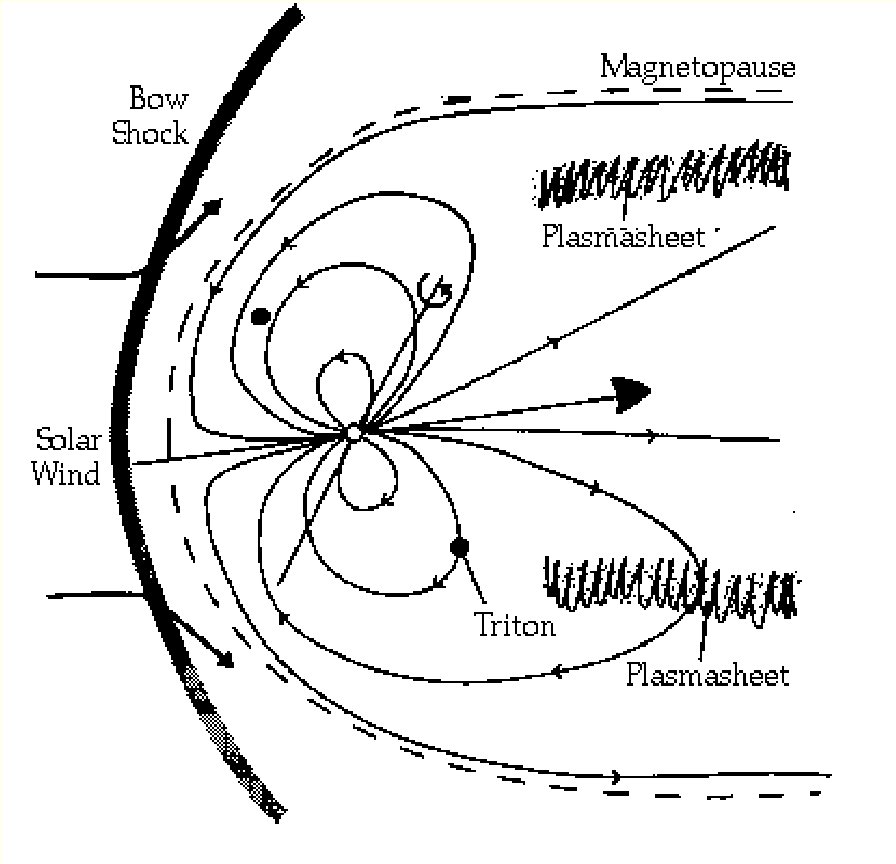


Photo from Hubble Space Telescope

- $r_N = 3{,}93\ r_E$
- $m_N = 17{,}2\ m_E$
- distance from sun : 30.1 AU
- gas giant with very dense atmosphere containing mainly methane
- 11 moons + ring system

Neptune

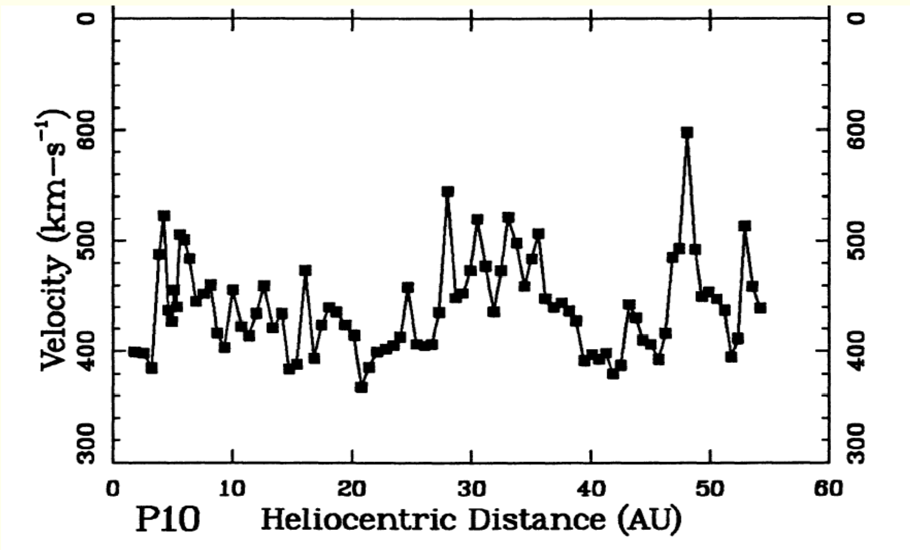




- magnetic field axis makes an angle of around 43° with rotational axis
- this gives enourmous daily variations of the structure of the magnetosphere also for Neptune

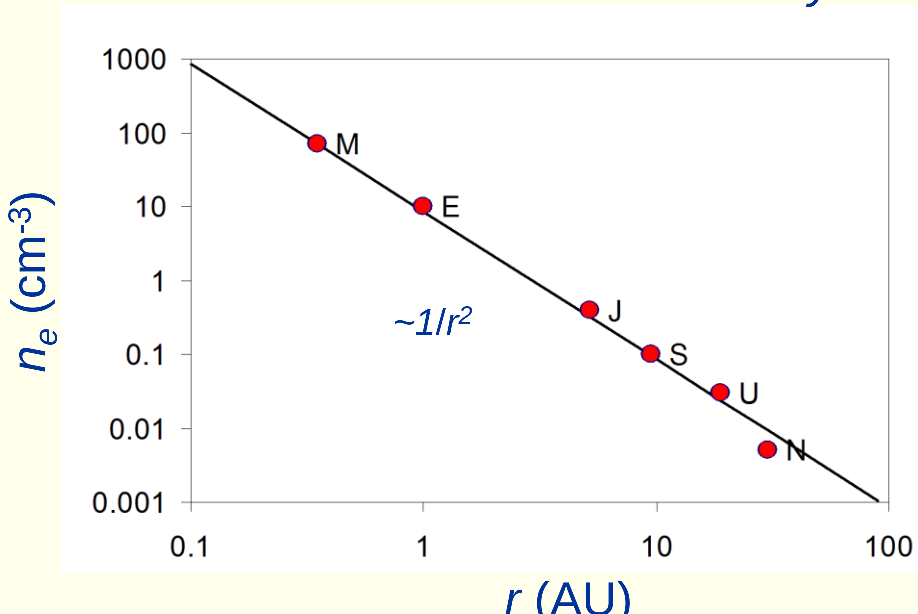
Comparative magnetospheres
Solar wind properties

Solar wind velocity

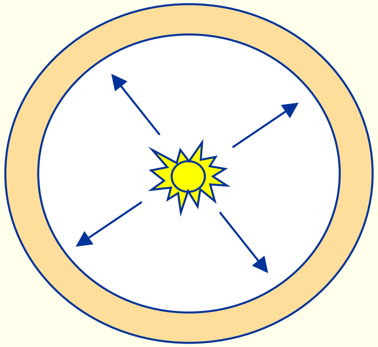


Pioneer 10, measurements
[Grazin et al., 1994]

Solar wind electron density



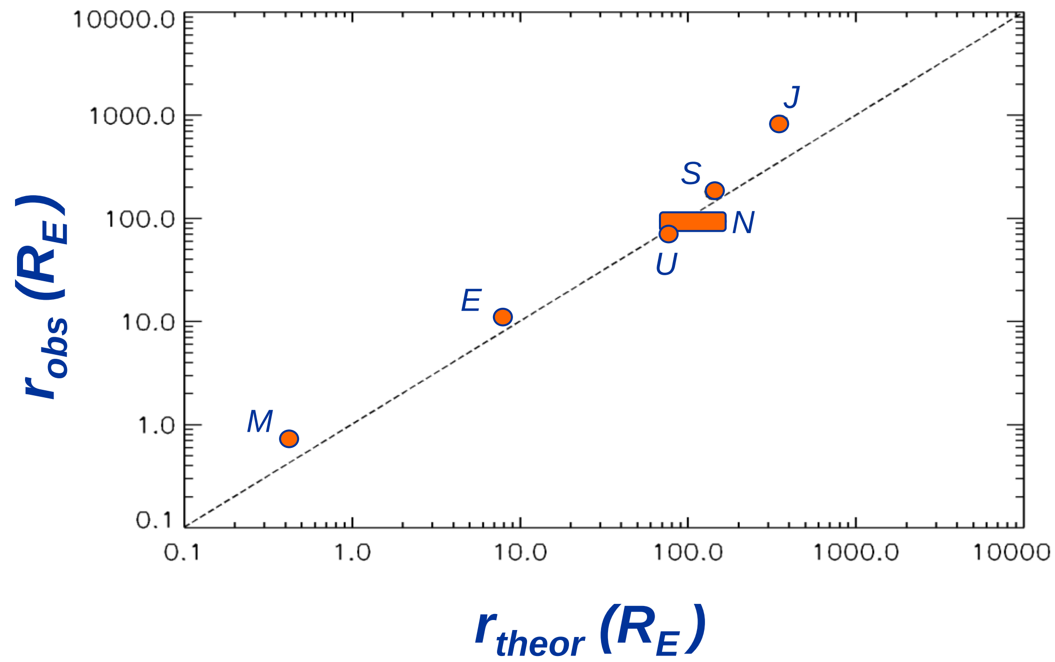
[Blanc et al., 2005]



$$dV = 4\pi r^2 dr$$

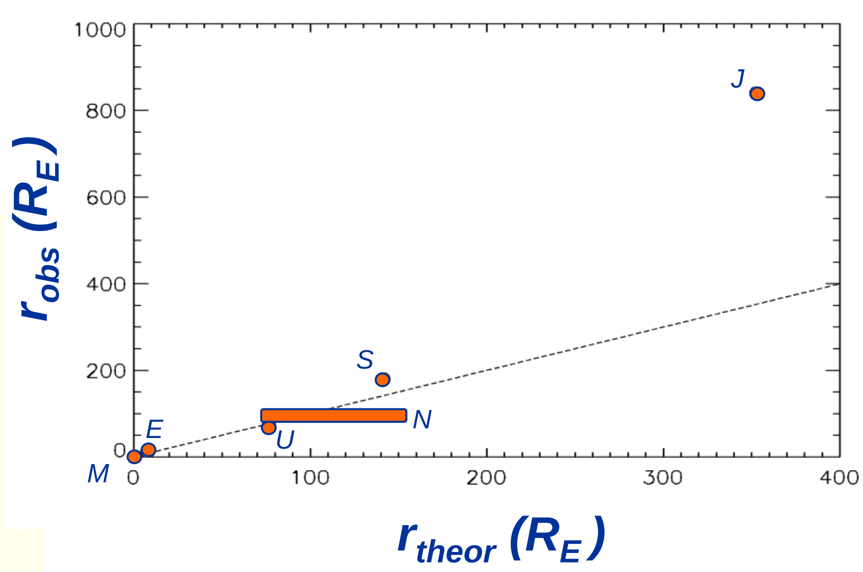
Comparative magnetospheres

Observed vs. theoretical standoff-distance



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

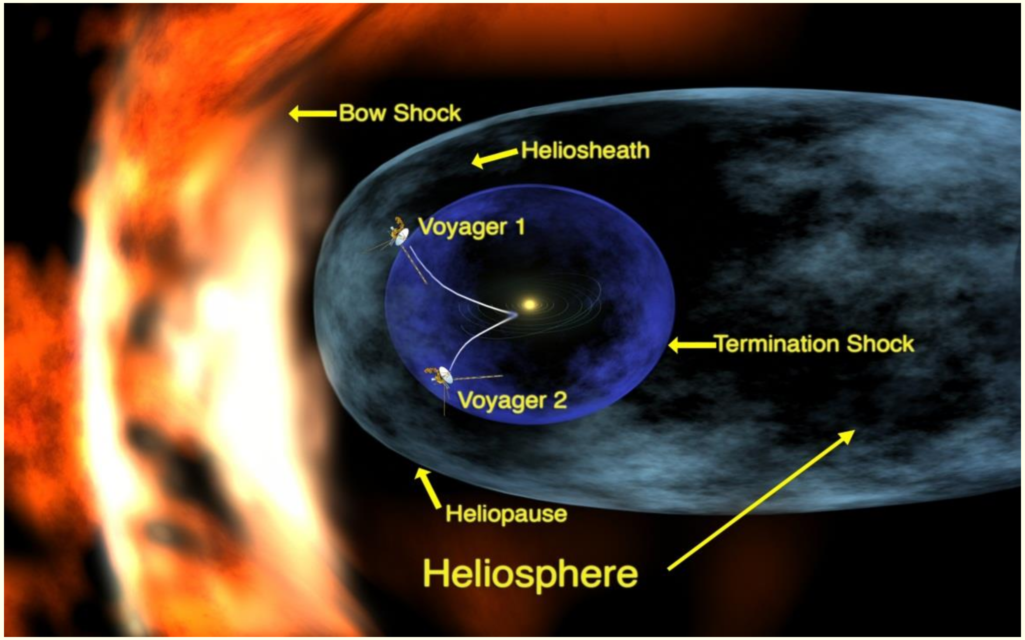
- *Model reasonably valid over three orders of magnitude*
- *Size of Jupiter's (and maybe Saturn's) magnetosphere underestimated*

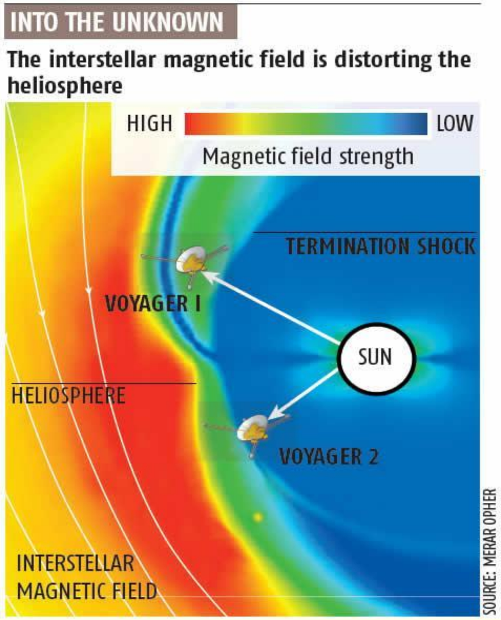


Other other magnetospheres

Heliosphere

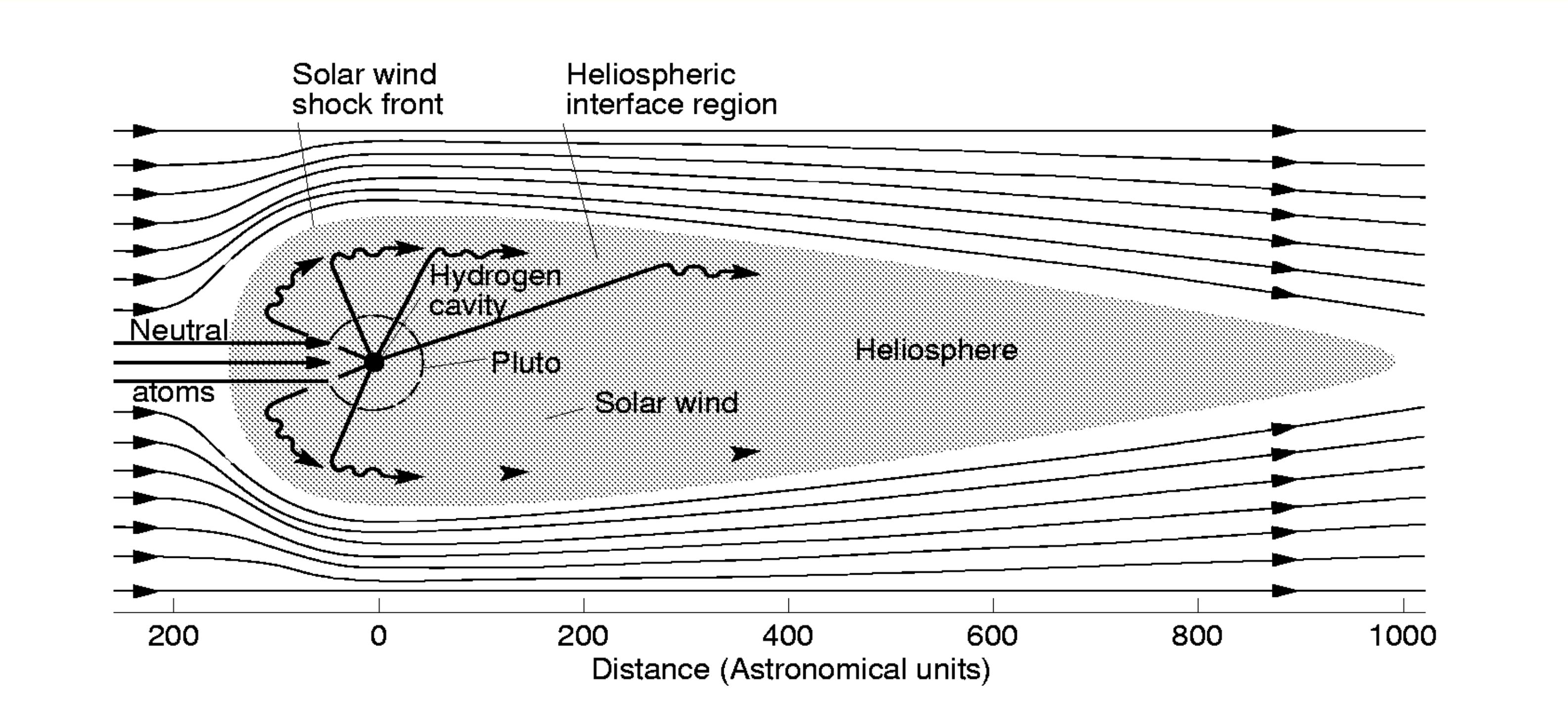
Interstellar wind





[Opher, 2007]

Heliosphere



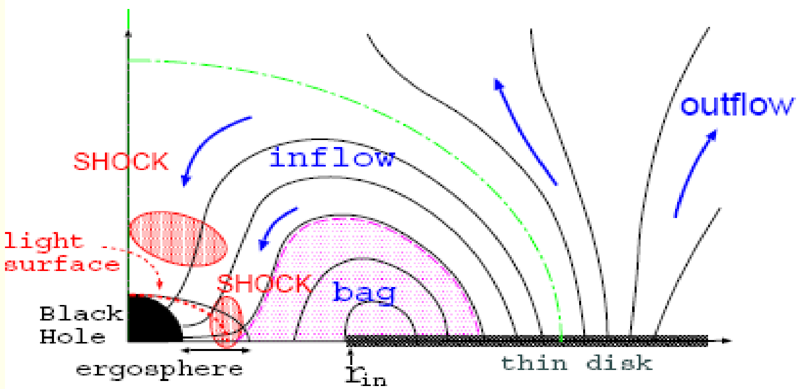
- Reaches approximately 100 AU into space (=1.5x10^{13} m)
- Voyager sonds are approaching/encountering the heliopause right now

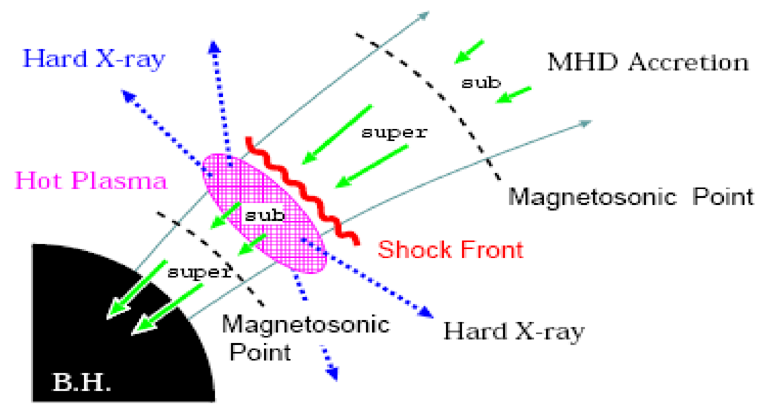
Other other magnetospheres

Exotic magnetospheres

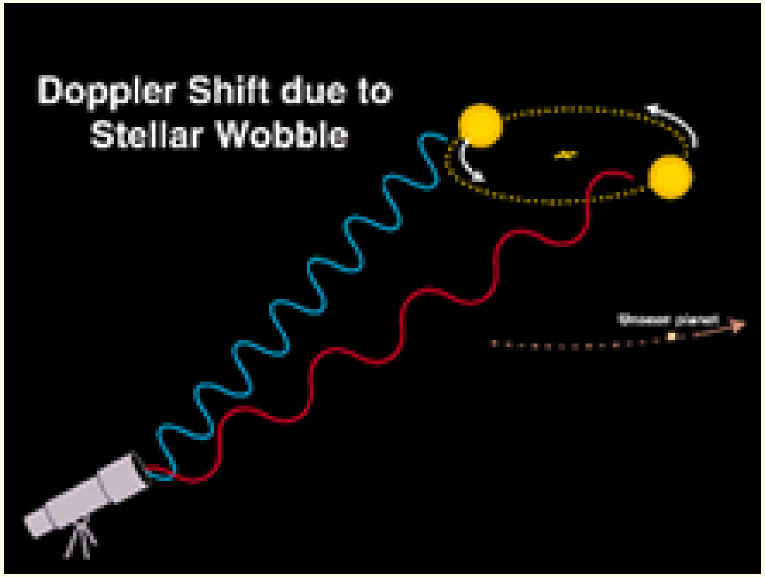
“Black Hole Magnetosphere” =

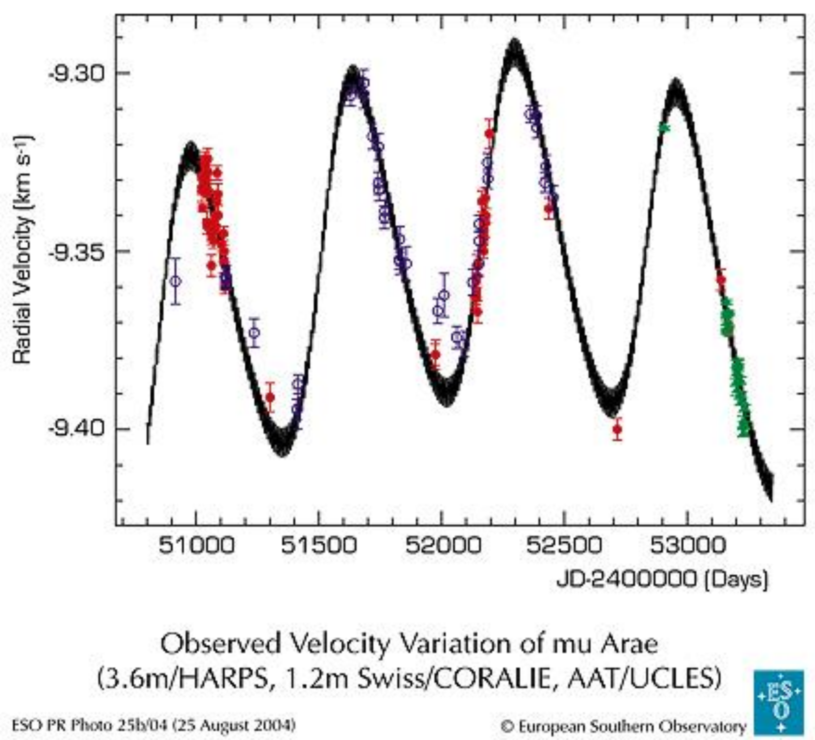
Loop (bag) + Disk–BH (inflow) + BH (Disk) – r_∞ (outflow)





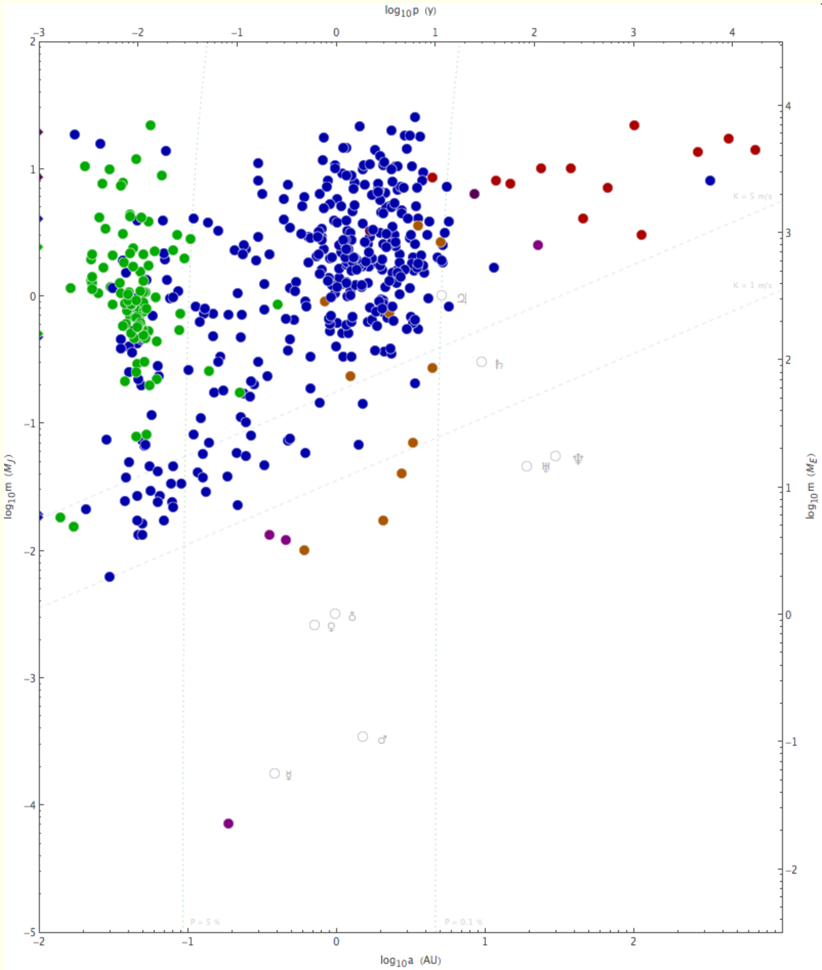
Exoplanets





Mostly detected by doppler shifts in starlight, or by dimming of the emitted starlight during transit of planet.

Magnetospheres of exoplanets

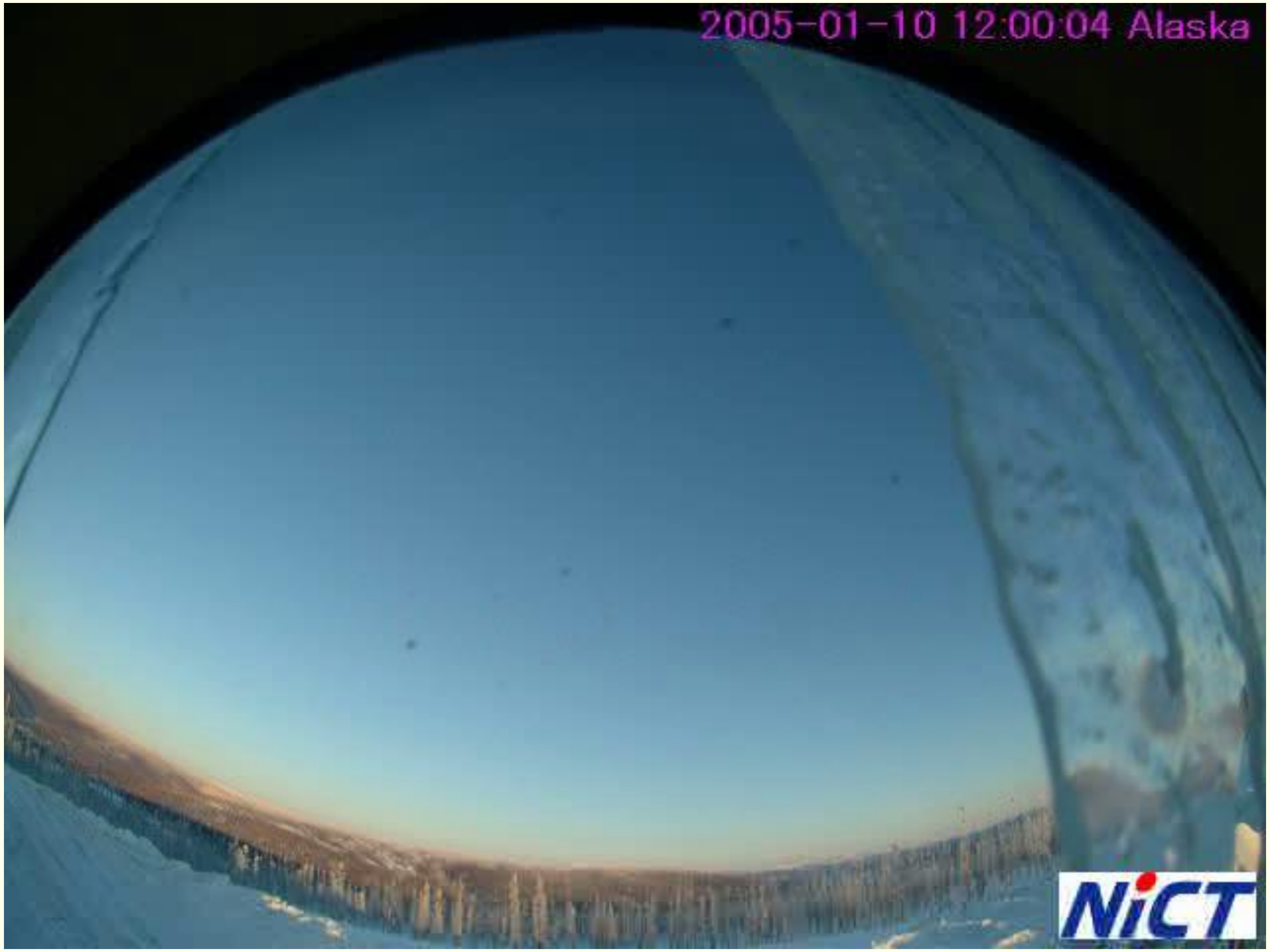


log *m*

log *a*

- 1958 exoplanets found up to September 24, 2015
- Nothing is known about their atmospheres, ionospheres or magnetospheres
- Can possibly be detected by
  - radio emissions from auroral activity or from radiation belts
  - spectroscopy when the magnetosphere is in front of its sun

The aurora

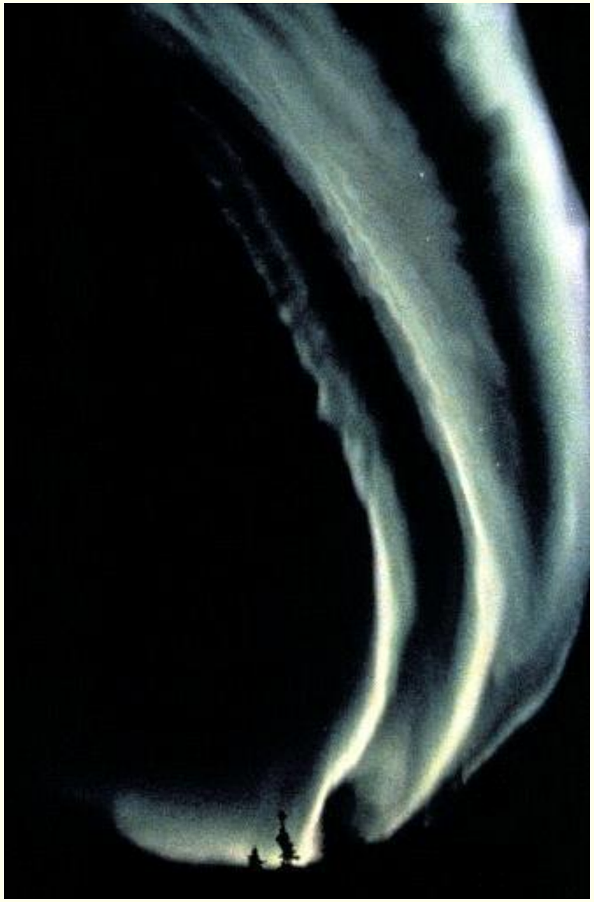


The aurora

The aurora

The aurora

Homogenous auroral arcs

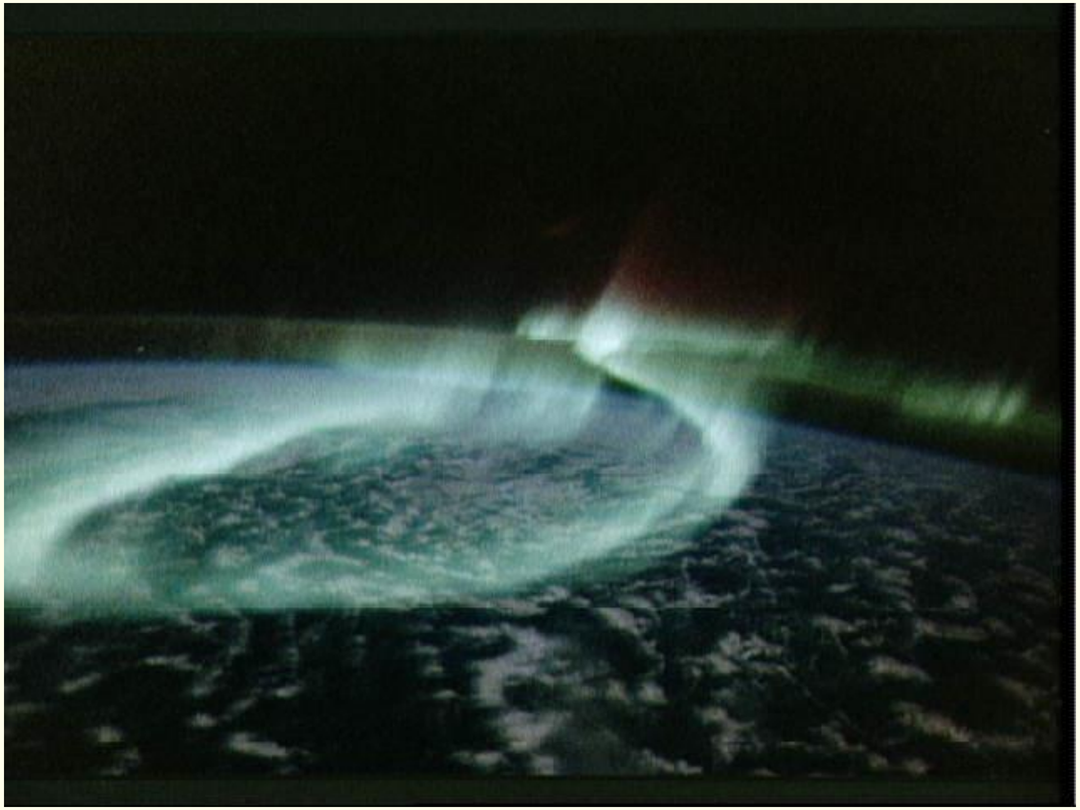


Rays, curtains

Rays are formed in the direction of the local magnetic field.

Drapes develop from homogenous arcs, often when they increase in intensity.

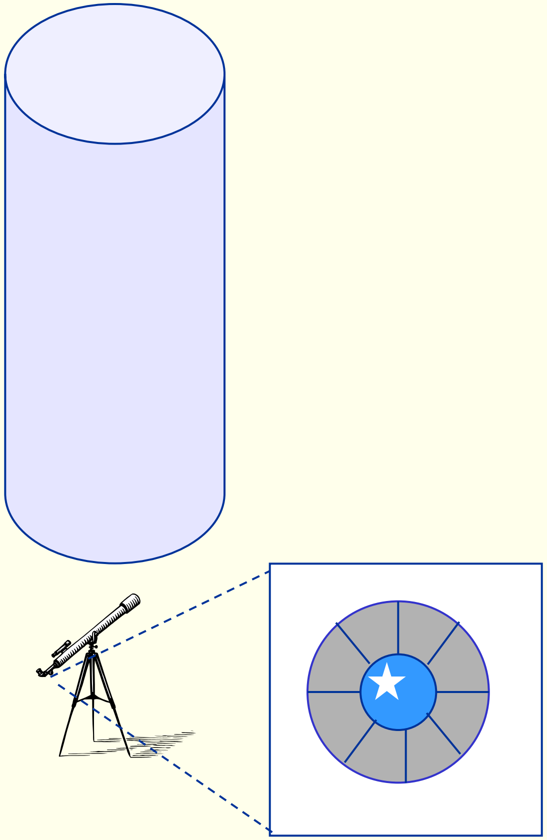
Auroral spirals



Develop when arcs become unstable

Auroral corona

Geometric effect of perspective when you look towards magnetic zenith. Compare the figure.



Aurora - altitude

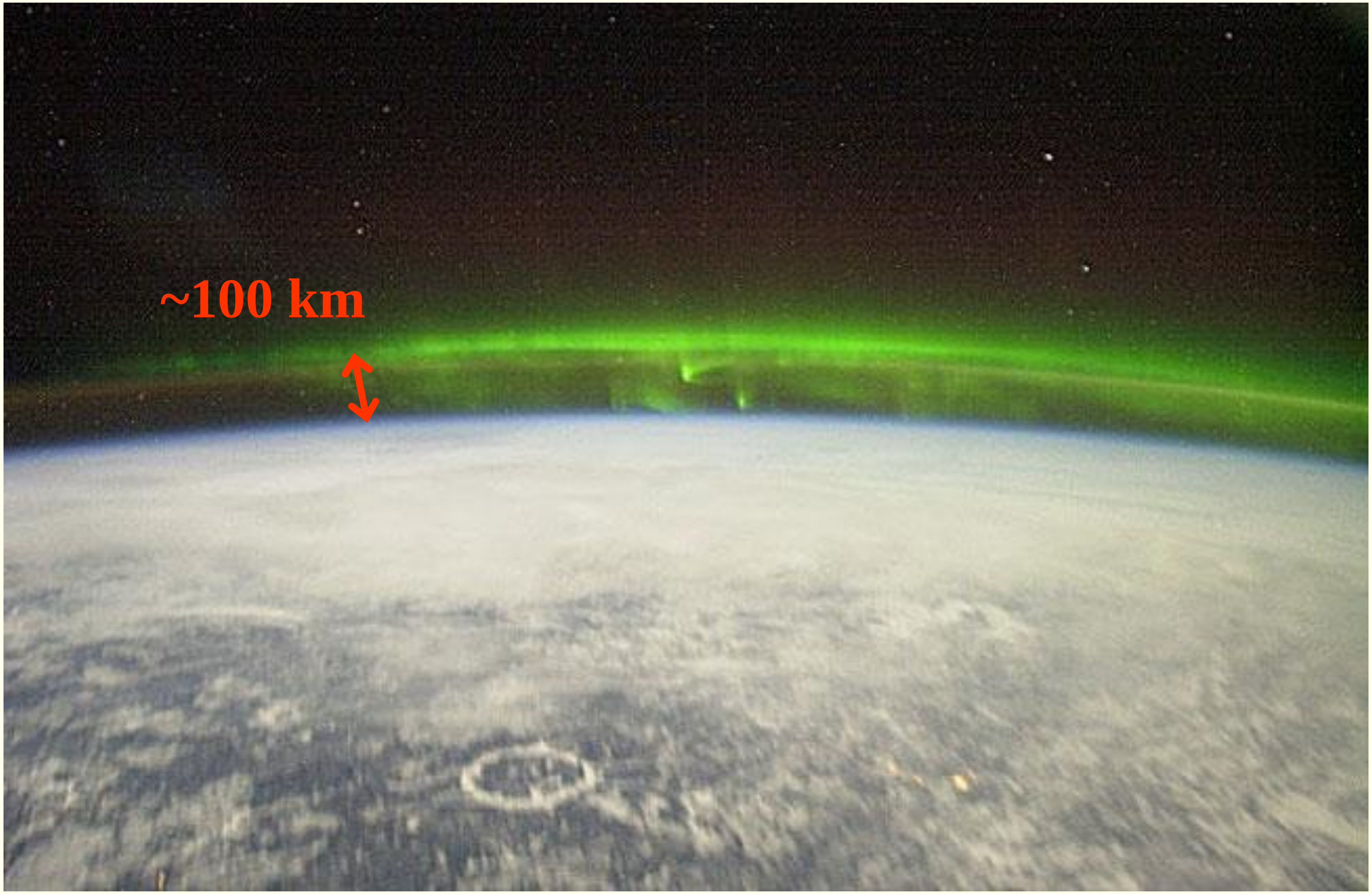


Foto from International Space Station

Early notions

Woodcut from Böhmen 1570.

Anders Celsius documented that compass needles where strongly affected during auroral activity in 1733.

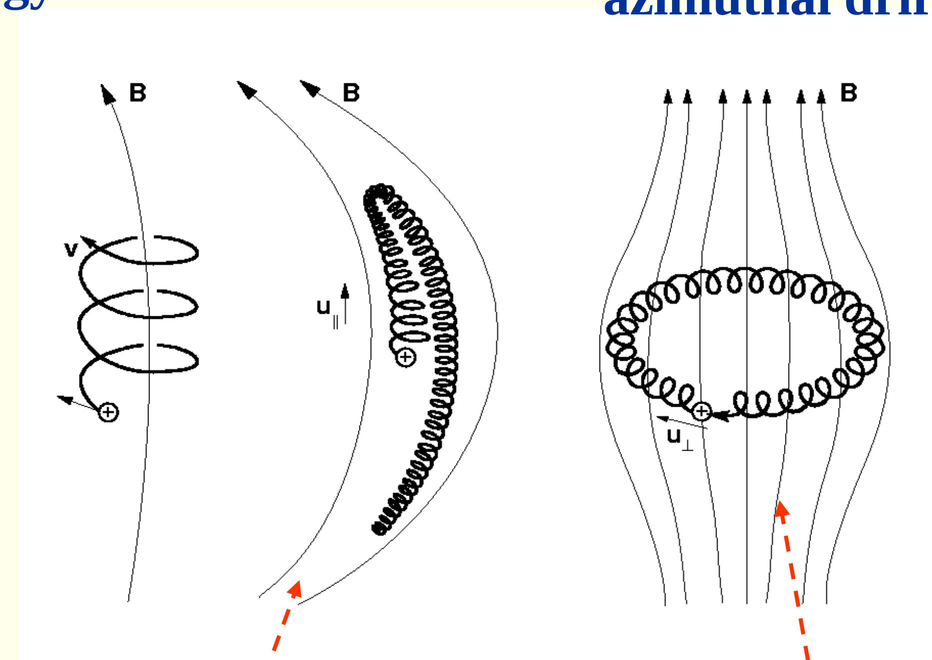
What causes the aurora?

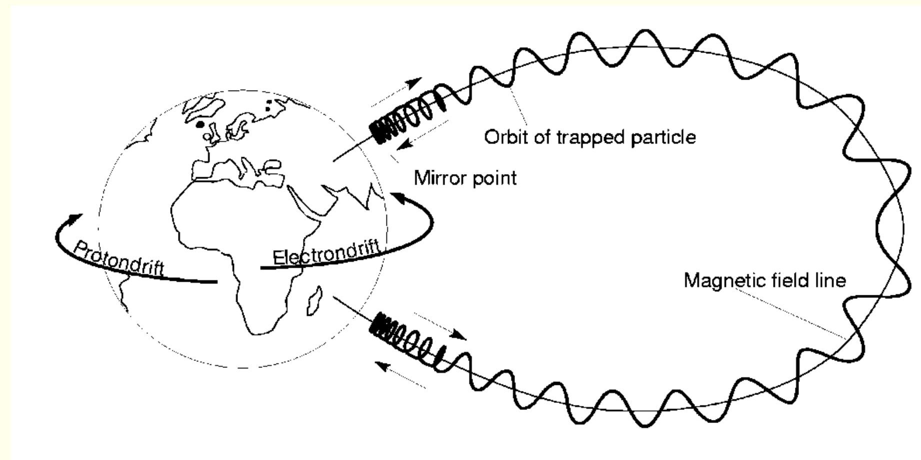
Particle motion in geomagnetic field

longitudinal oscillation

gyration

azimuthal drift

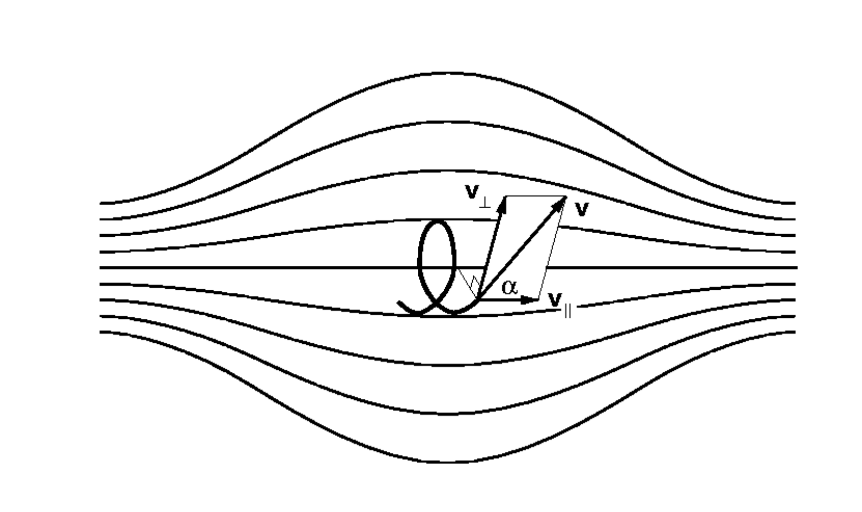




Magnetic mirror

grad B drift

Magnetic mirror



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

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

particle turns when α = 90° →

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

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

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

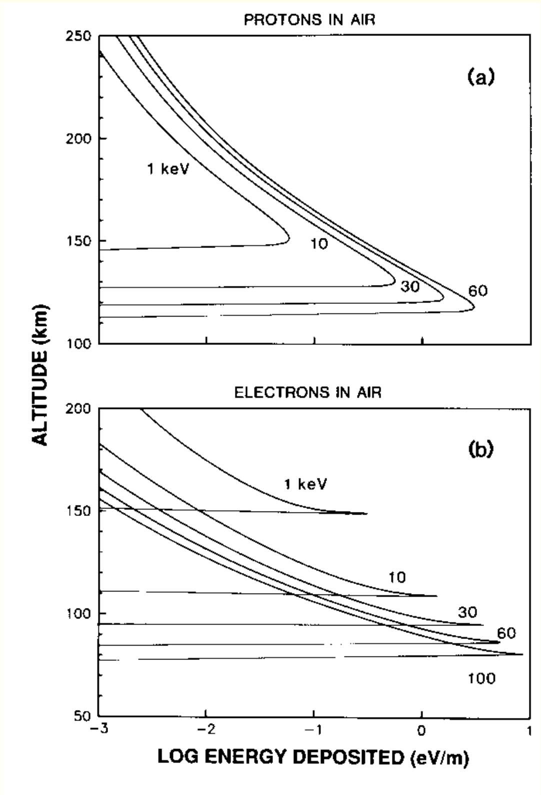
Particles in ***loss cone*** :

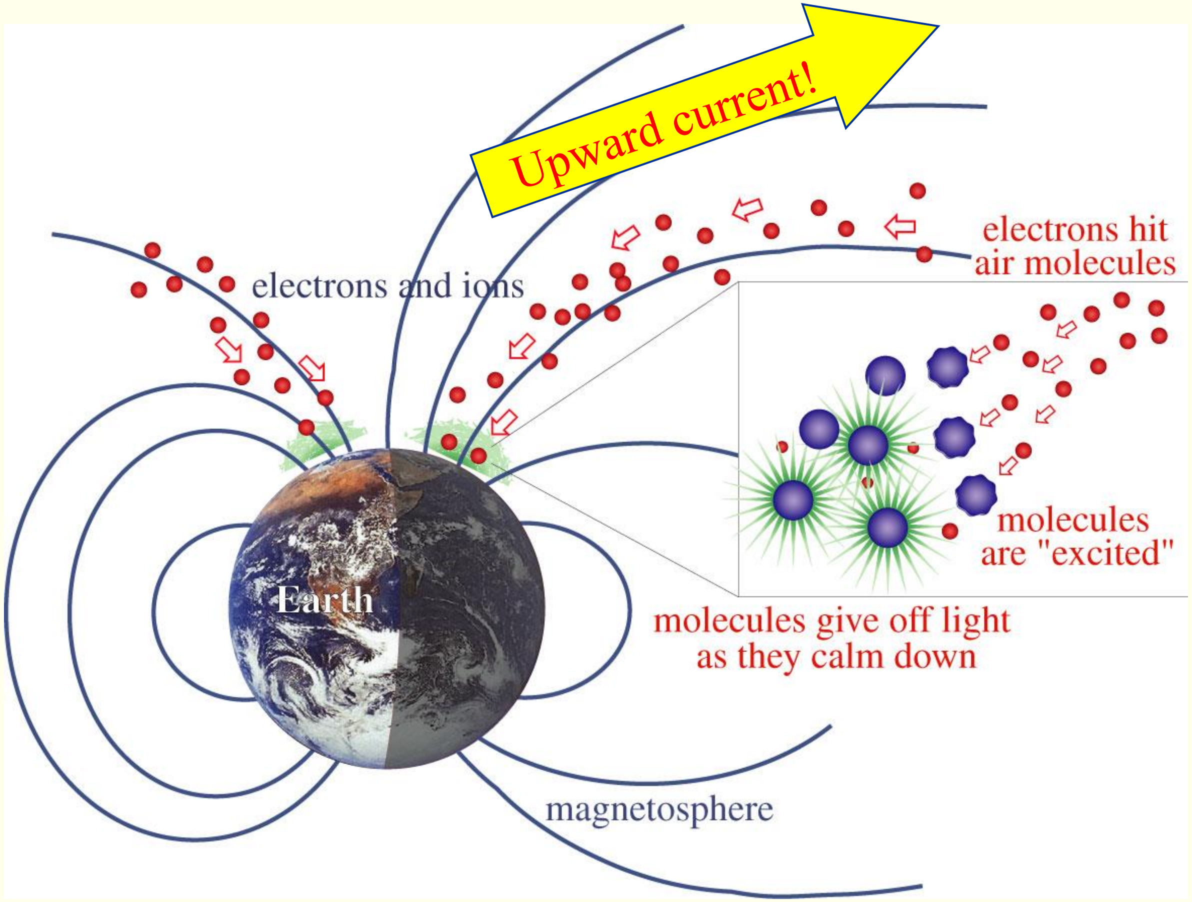
$$\alpha < \alpha_{lc}$$

The magnetic moment μ is an ***adiabatic invariant***.

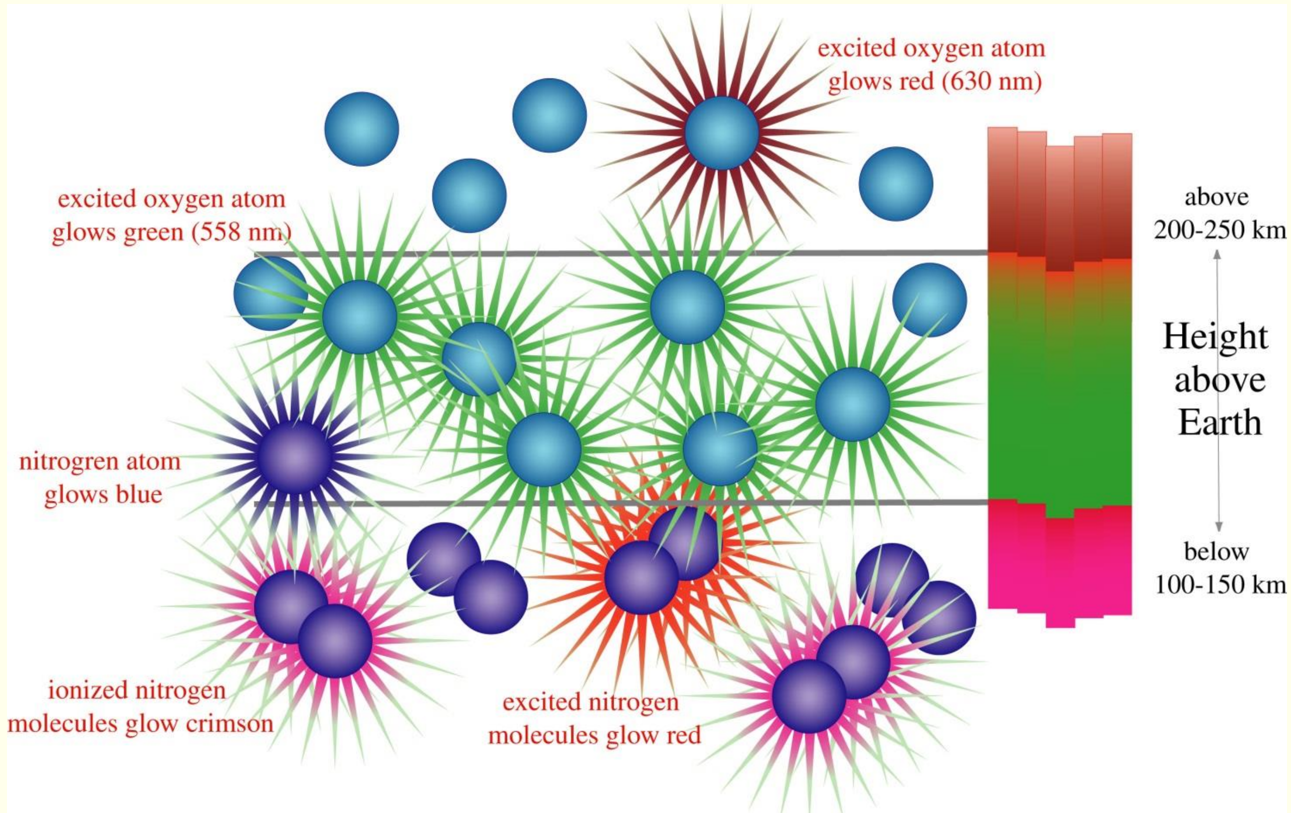
$$\mu = \frac{mv_\perp^2}{2B} = \frac{mv^2\sin^2\alpha}{2B}$$

Collisions - emissions

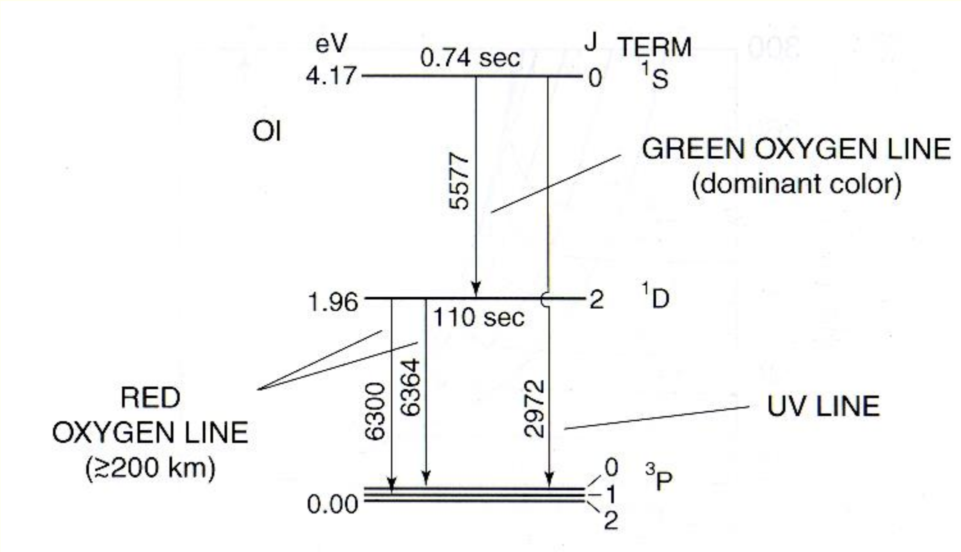


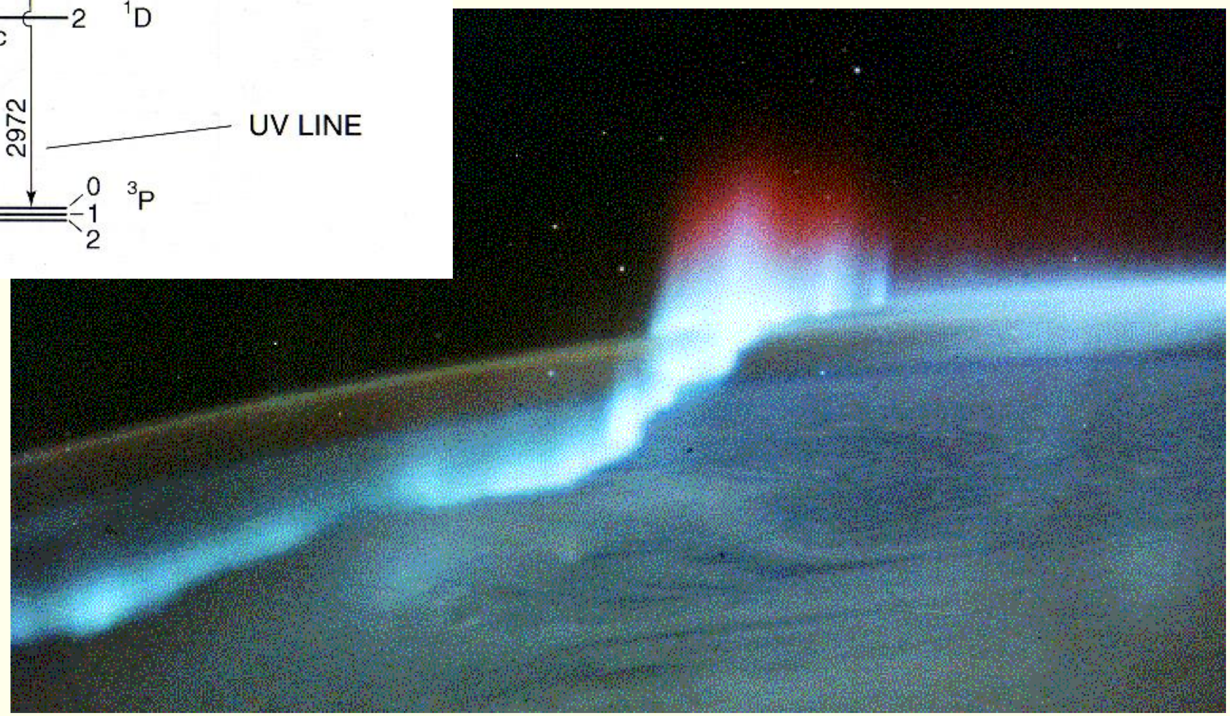


Emissions

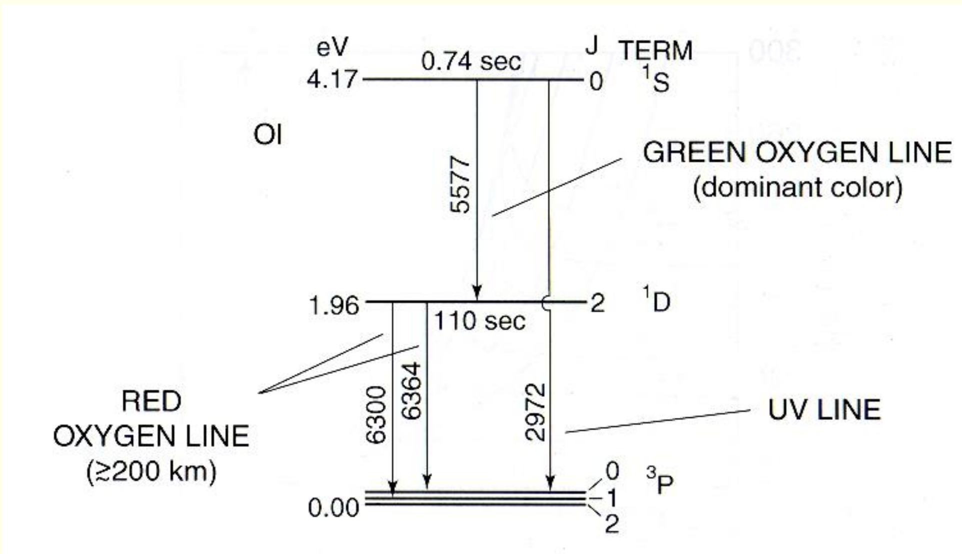

excited oxygen atom
glows red (630 nm)
excited oxygen atom
glows green (558 nm)
nitrogren atom
glows blue
ionized nitrogen
molecules glow crimson
excited nitrogen
molecules glow red
above
200-250 km
Height
above
Earth
below
100-150 km

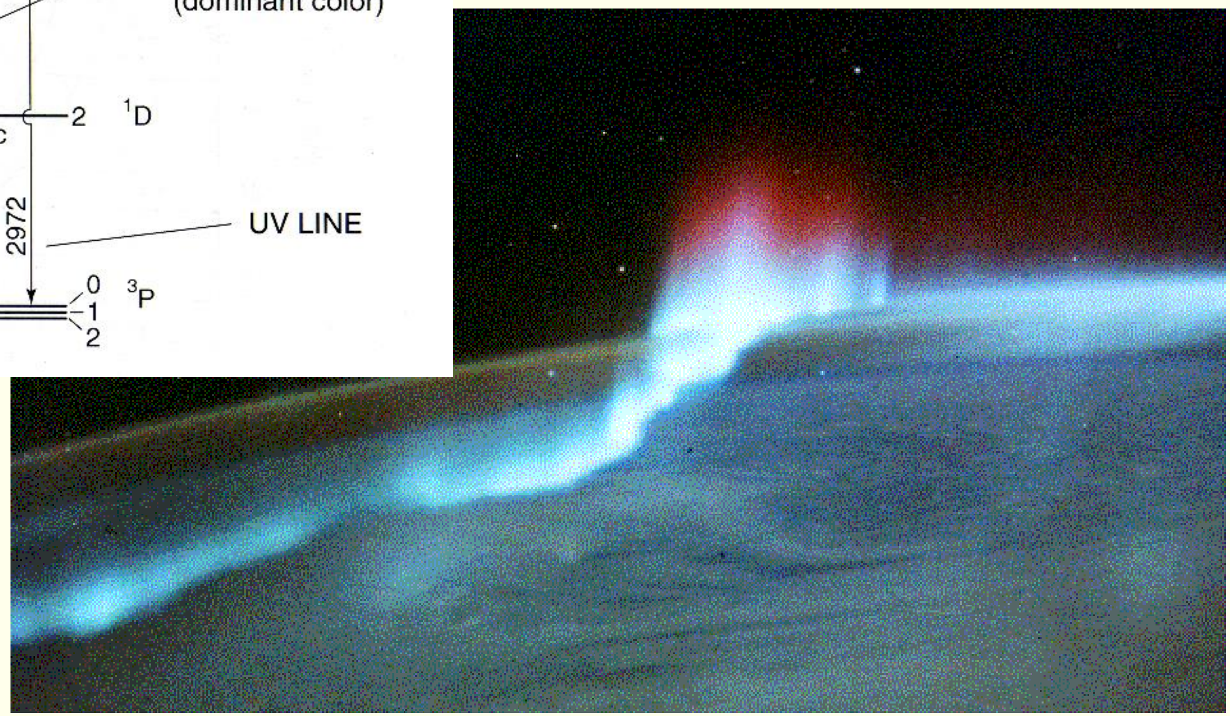
Oxygen emissions



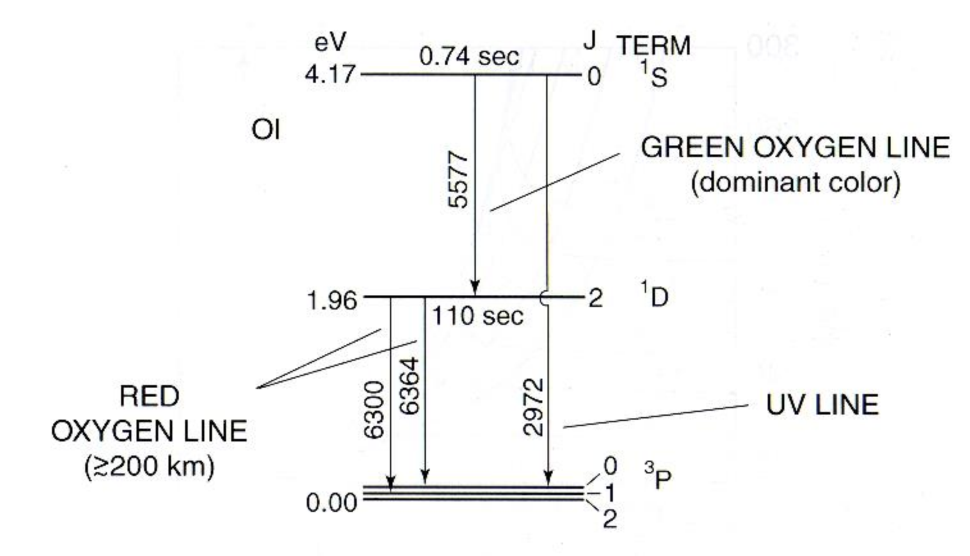


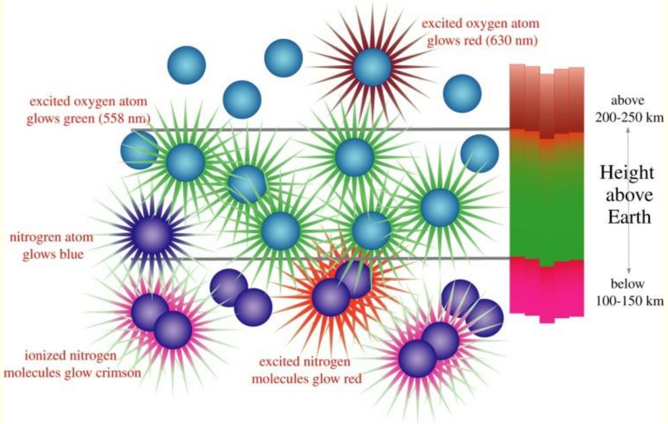
Why is there no red emissions at lower altitude?



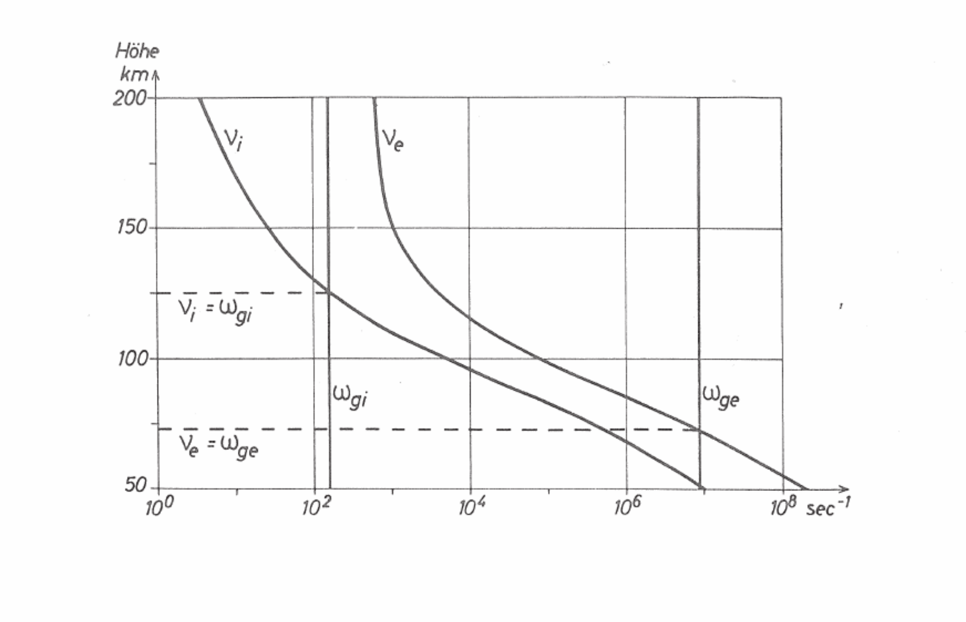


Oxygen emissions





The red emission line is suppressed by collisions at lower altitudes due the its long transition time. (When an excited atom collides with another atom, is is de-excited without any emission.)



Larger scales

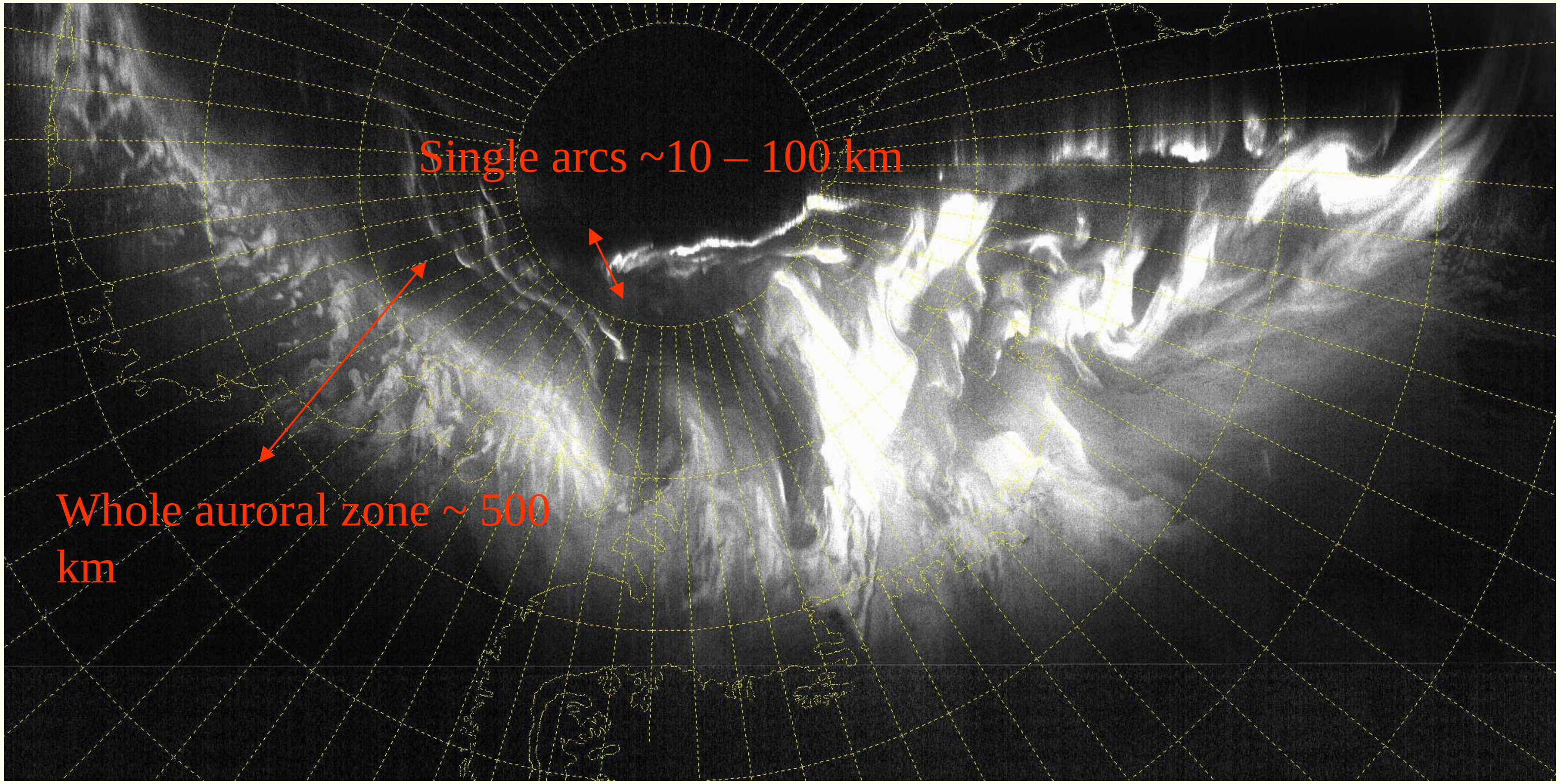
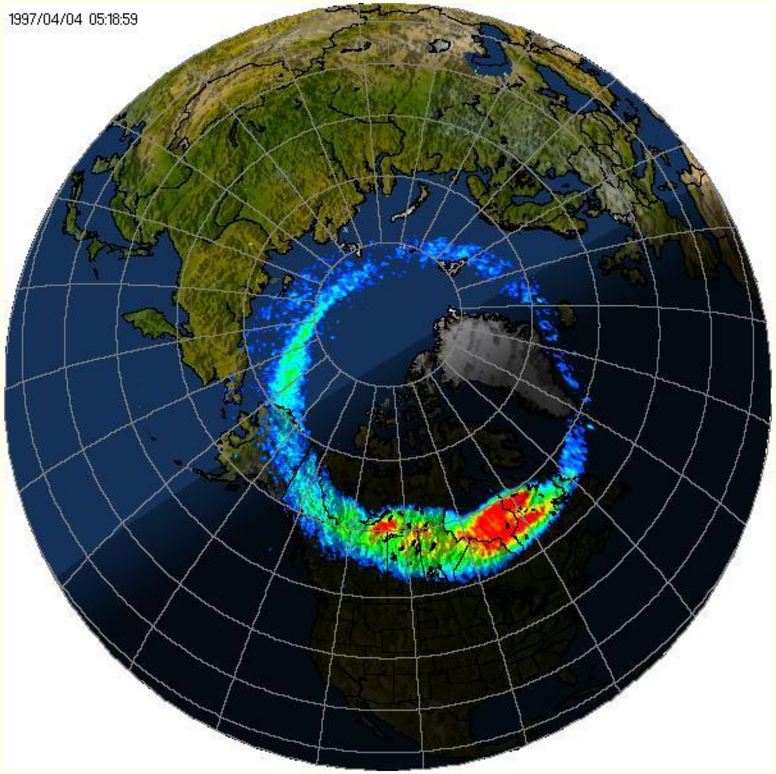
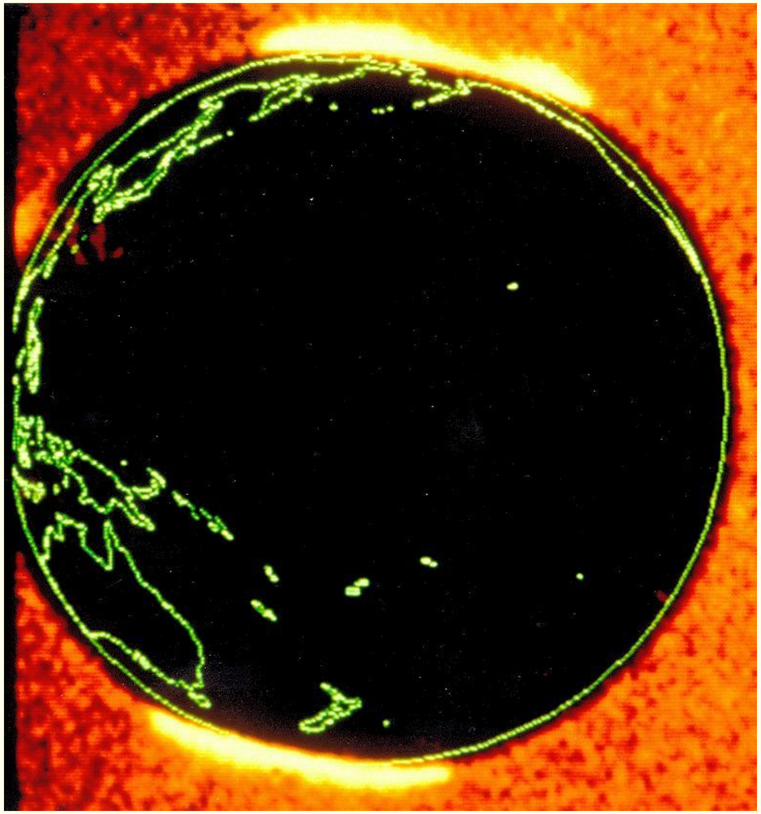


Foto från DMSP-satelliten

Auroral ovals



Polar

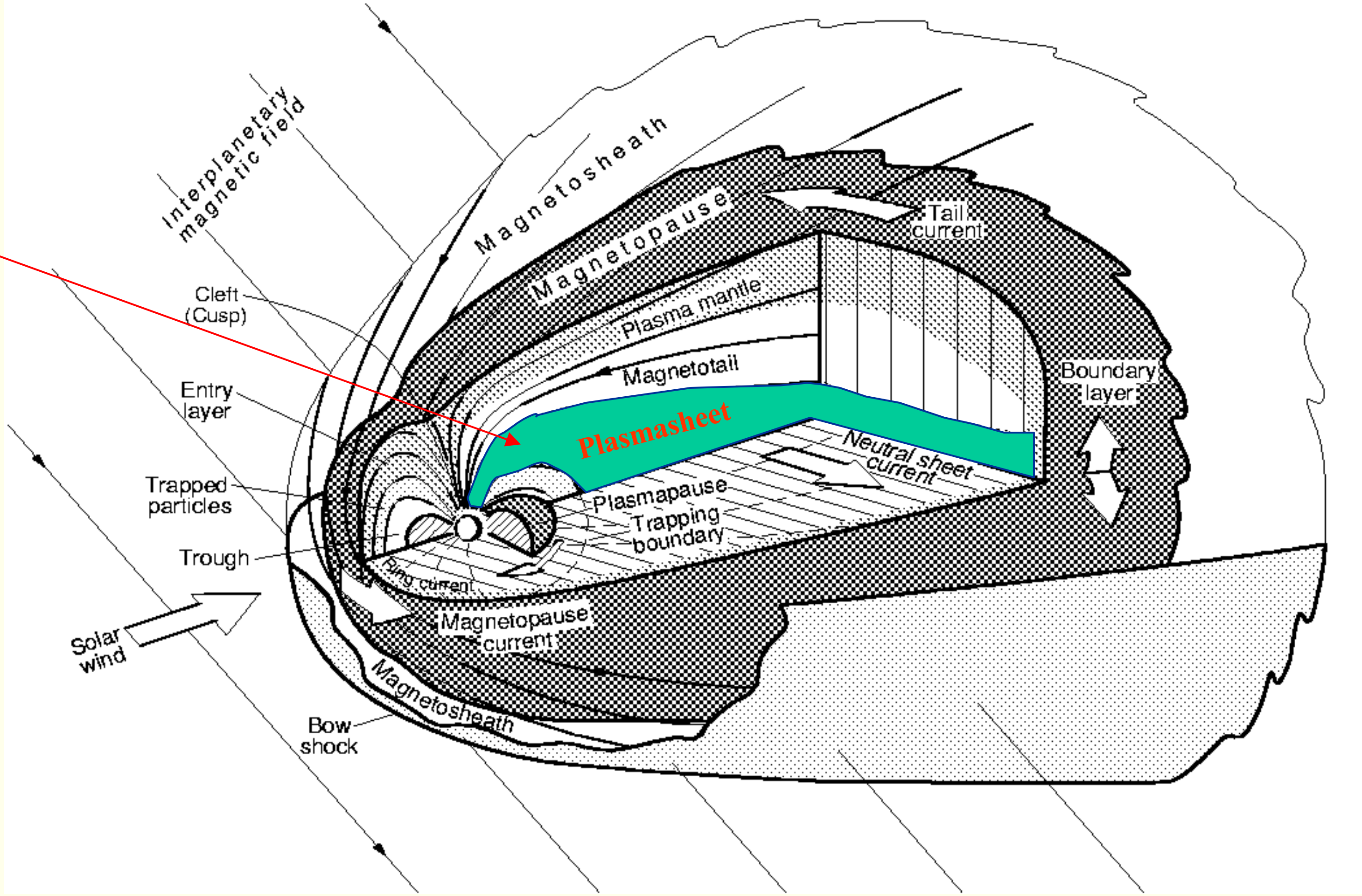


Dynamics Explorer

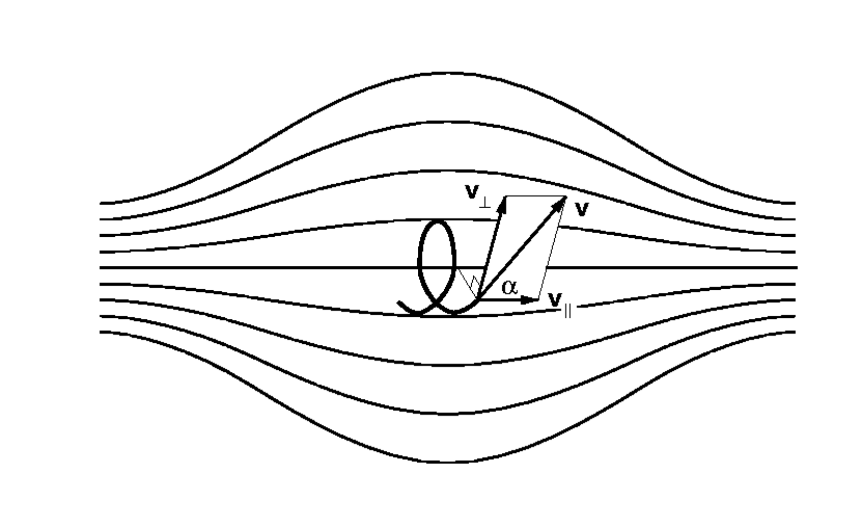
The auroral oval is the projection of the plasmasheet onto the atmosphere

Mystery!

The particles in the plasmasheet do not have high enough energy to create aurora visible to the eye.



Magnetic mirror



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particle turns when α = 90° →

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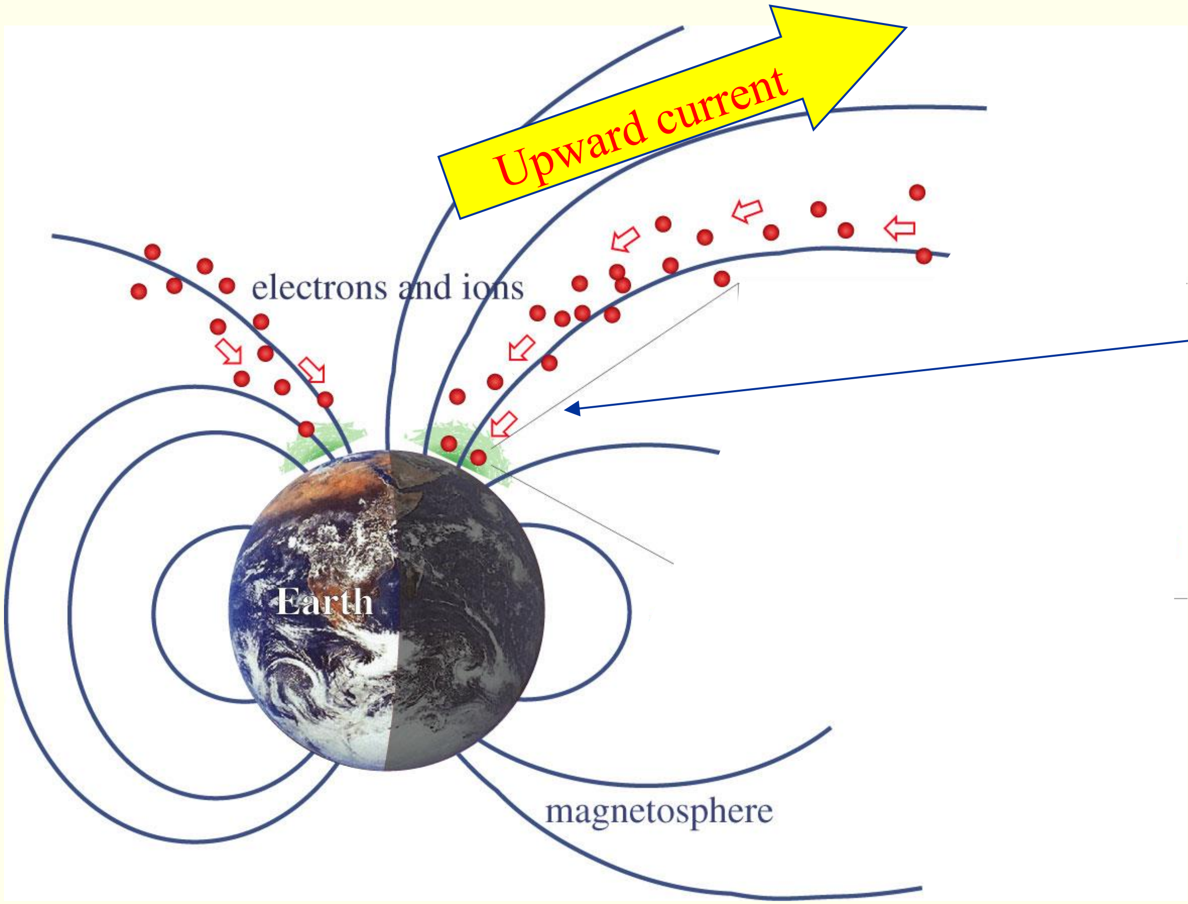
Particles in ***loss cone*** :

$$\alpha < \alpha_{fl}$$

The magnetic moment μ is an ***adiabatic invariant***.

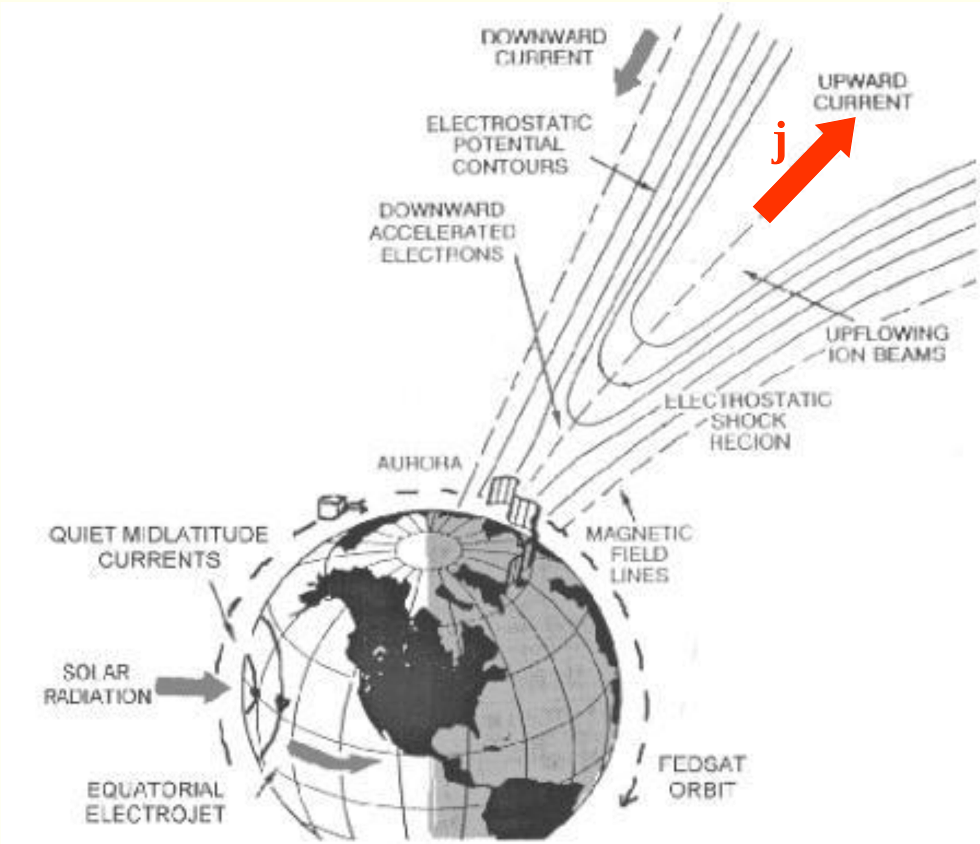
$$\mu = \frac{mv_\perp^2}{2B} = \frac{mv^2\sin^2\alpha}{2B}$$

Why particle acceleration?



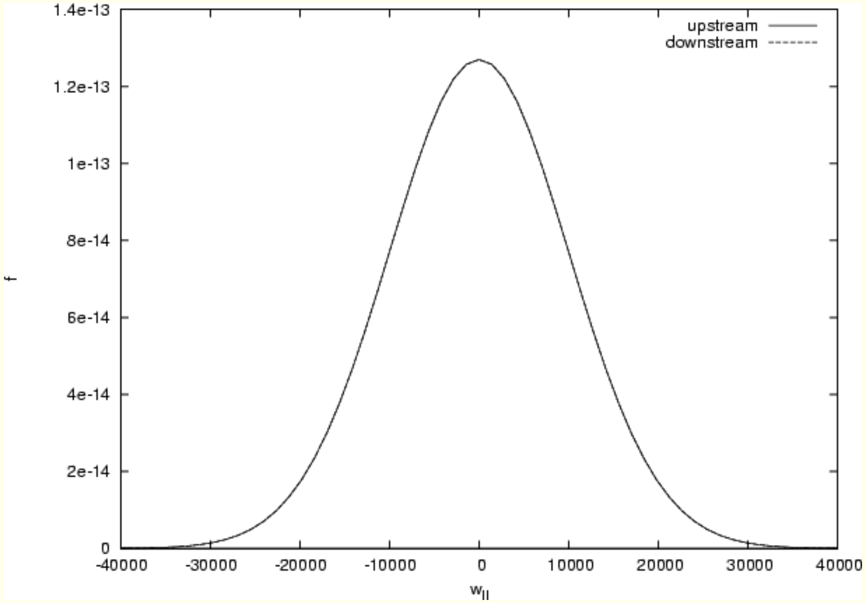
- The magnetosphere often seems to act as a current generator.
- The lower down you are on the field line, the more particles have been reflected by the magnetic mirror.
- At low altitudes there are not enough electrons to carry the current.

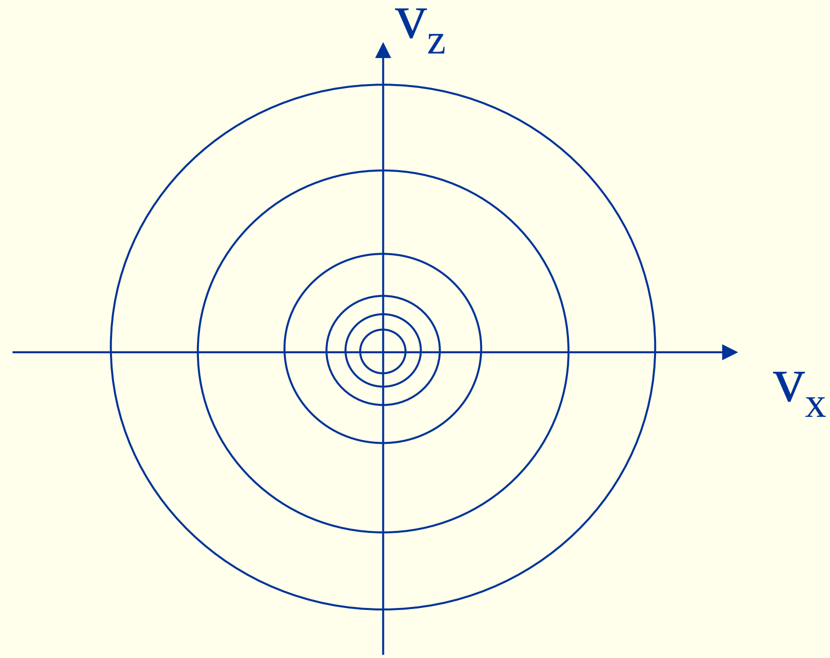
Why particle acceleration?



- Electrons are accelerated downwards by upward E-field.
- This increases the pitch-angle of the electrons, and more electrons can reach the ionosphere, where the current can be closed.

Distribution function

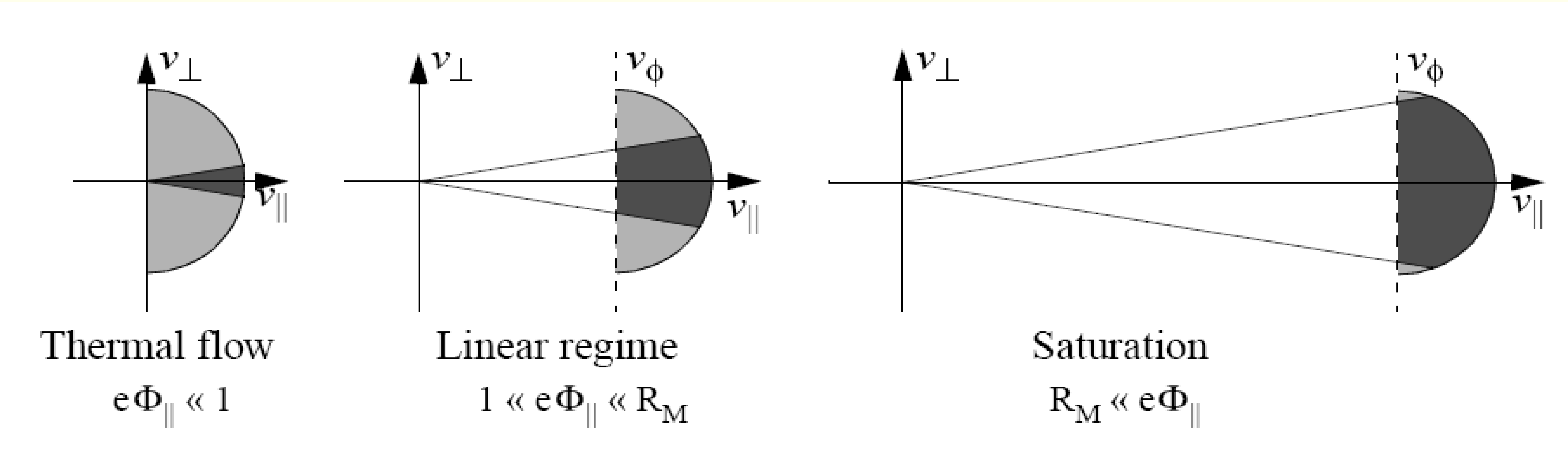




Example:
Maxwellian distribution

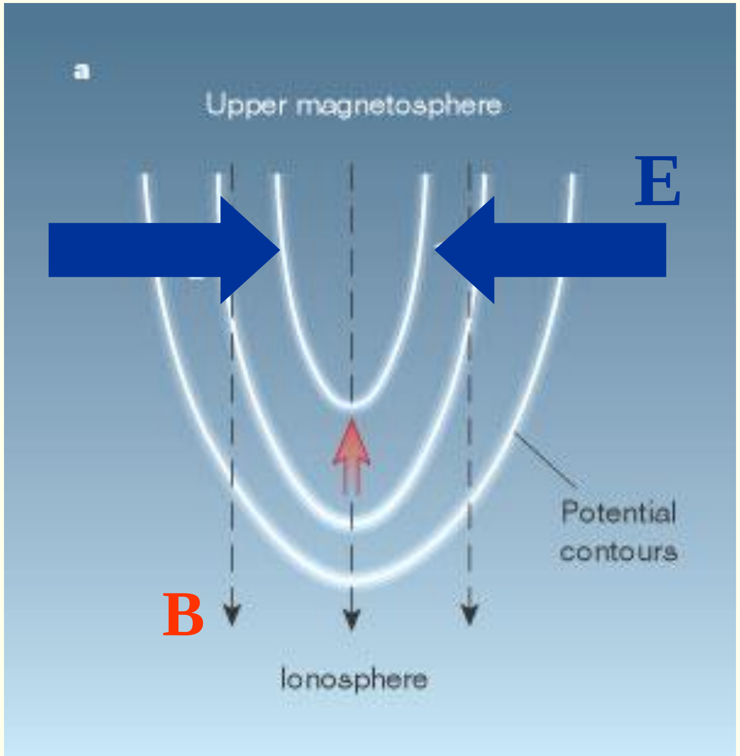
$$f = \frac{n}{\sqrt{(2\pi RT)^3}} \exp\left(-\frac{m(v_x^2 + v_y^2 + v_z^2)}{2kT}\right)$$

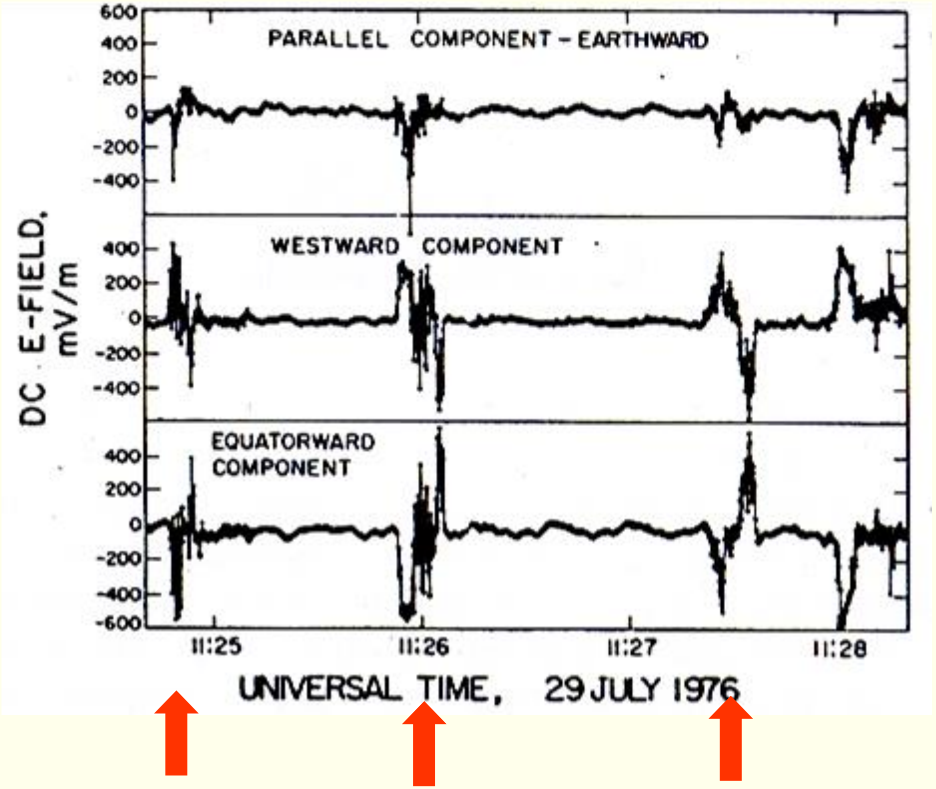
Why particle acceleration?



- Electrons are accelerated downwards by upward E-field.
- This increases the pitch-angle of the electrons, and more electrons can reach the ionosphere, where the current can be closed.

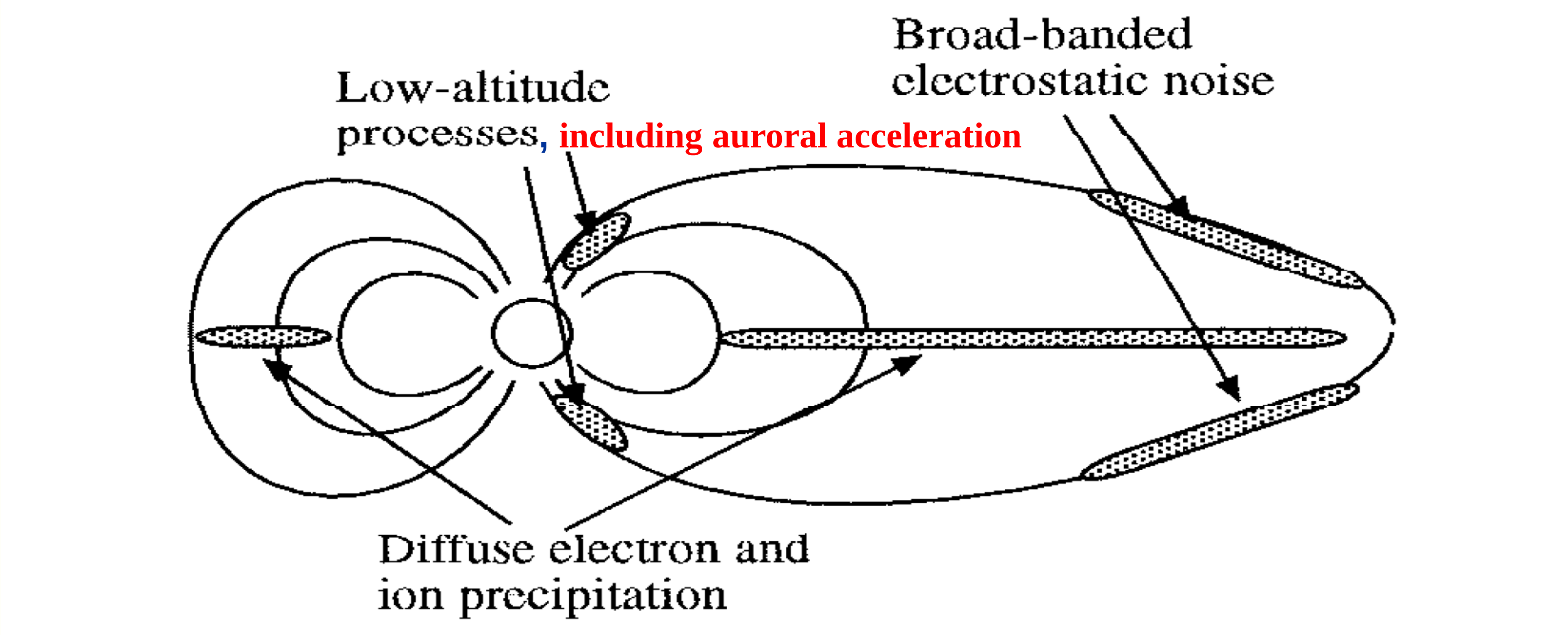
Satellite signatures of U potential





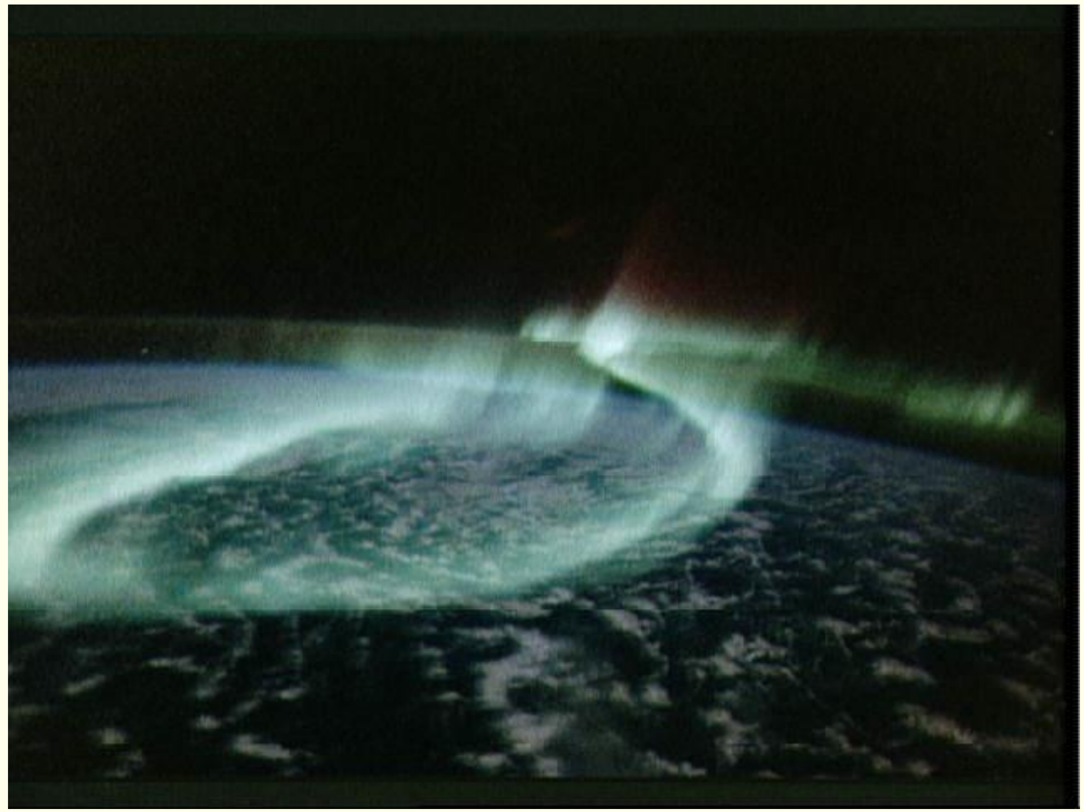
Measurements made by the ISEE satellite (Mozer et al., 1977)

Acceleration regions



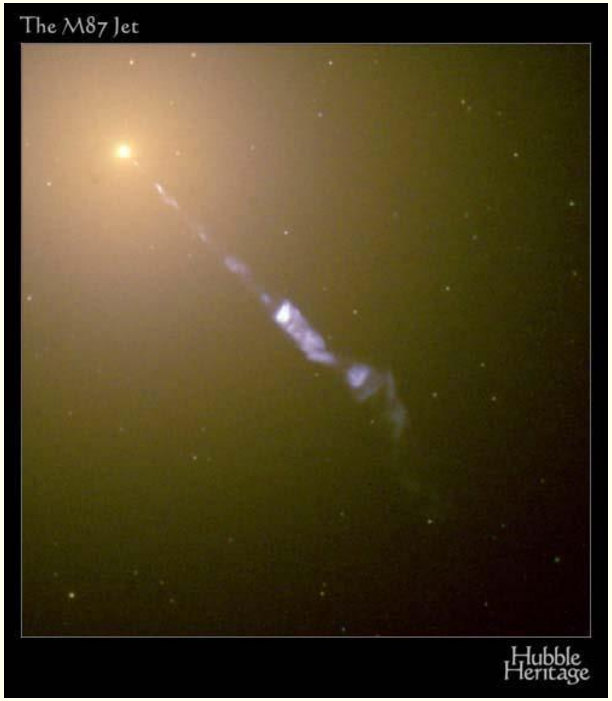
Auroral acceleration region typically situated at altitude of 1-3 R_E

Auroral spirals

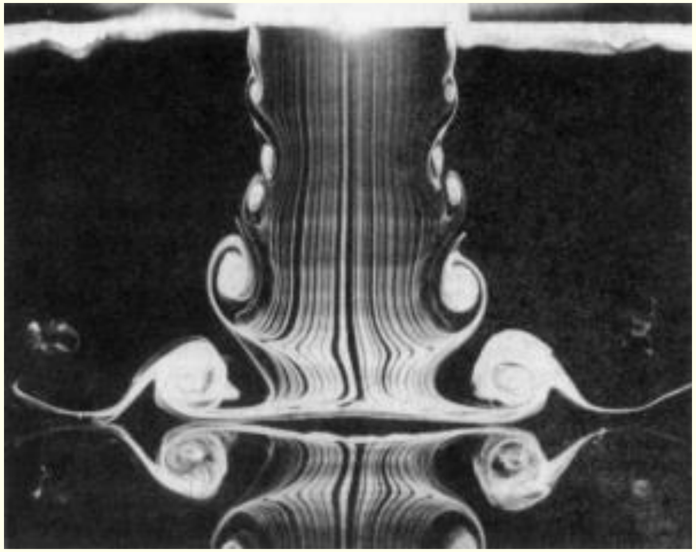


Develop when arcs become unstable

Kelvin-Helmholz-instability – a general phenomenon



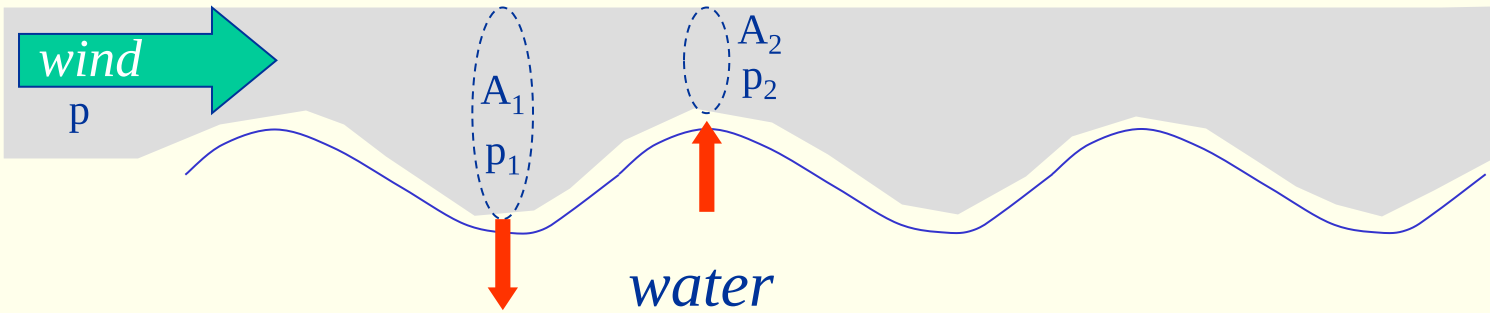
Extragalactic jet (M87)



Aero- and fluid dynamics

Cluds

Kelvin-Helmholz instability
Example: water waves



Continuity equation:

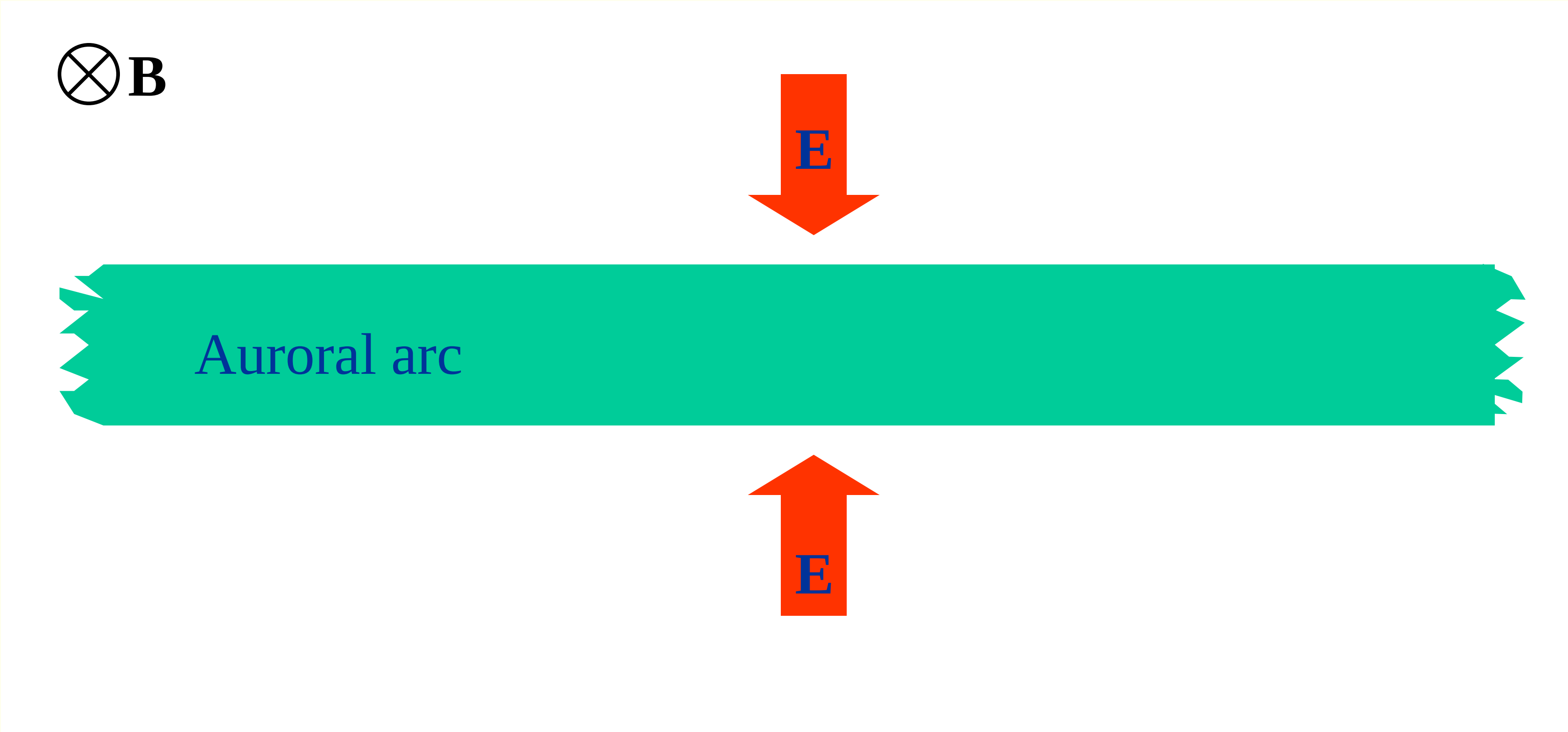
$$A_1 v_1 = A_2 v_2$$

Bernoulli's equation:

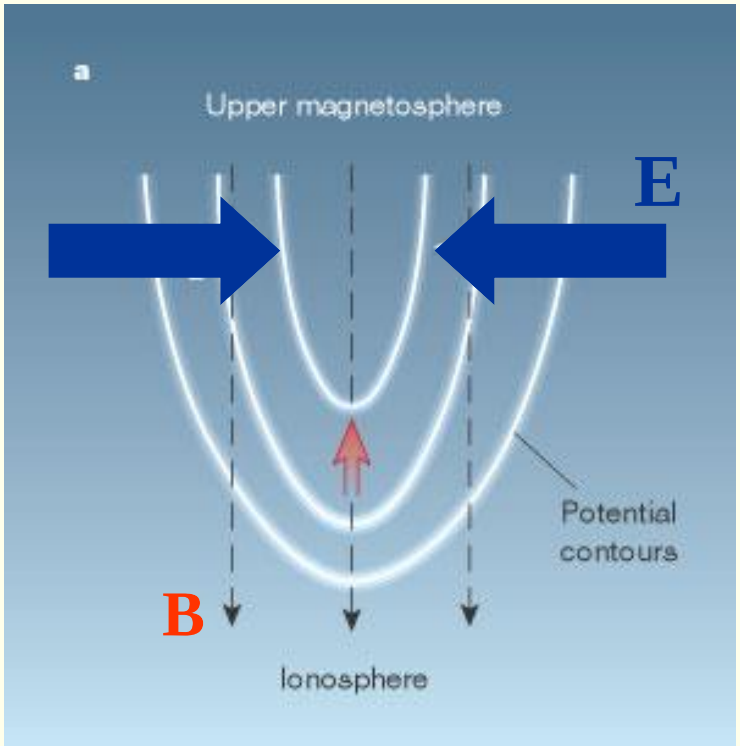
$$p_1 + \rho v_1^2 = p_2 + \rho v_2^2 = const.$$

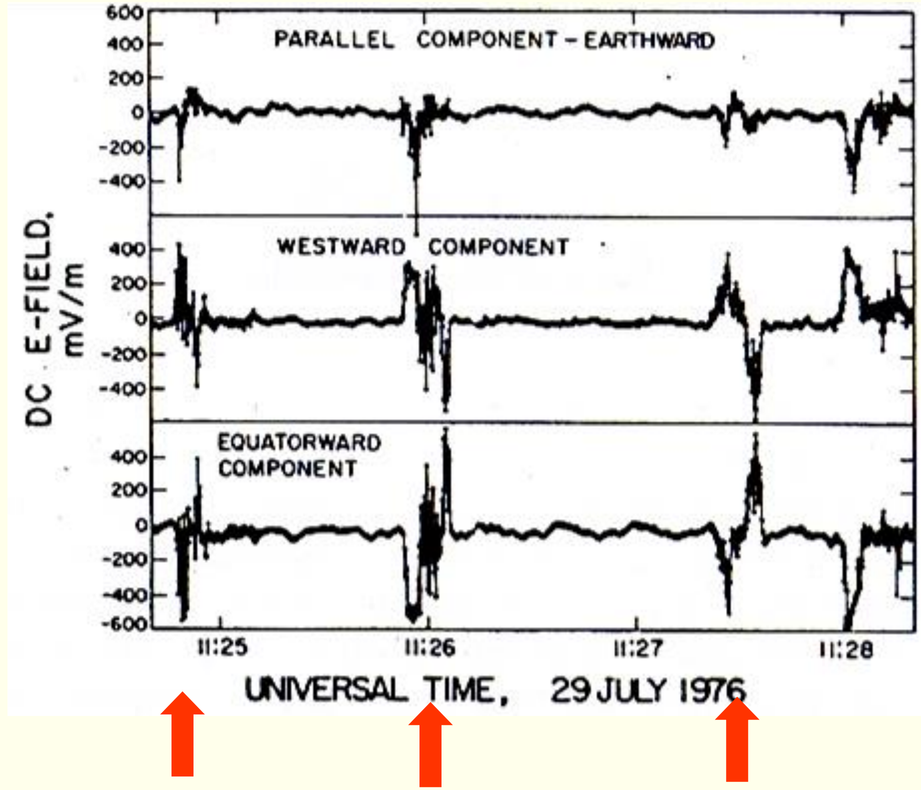
$$\because p_1 > p > p_2$$

Spirals – Kelvin-Helmholz instability



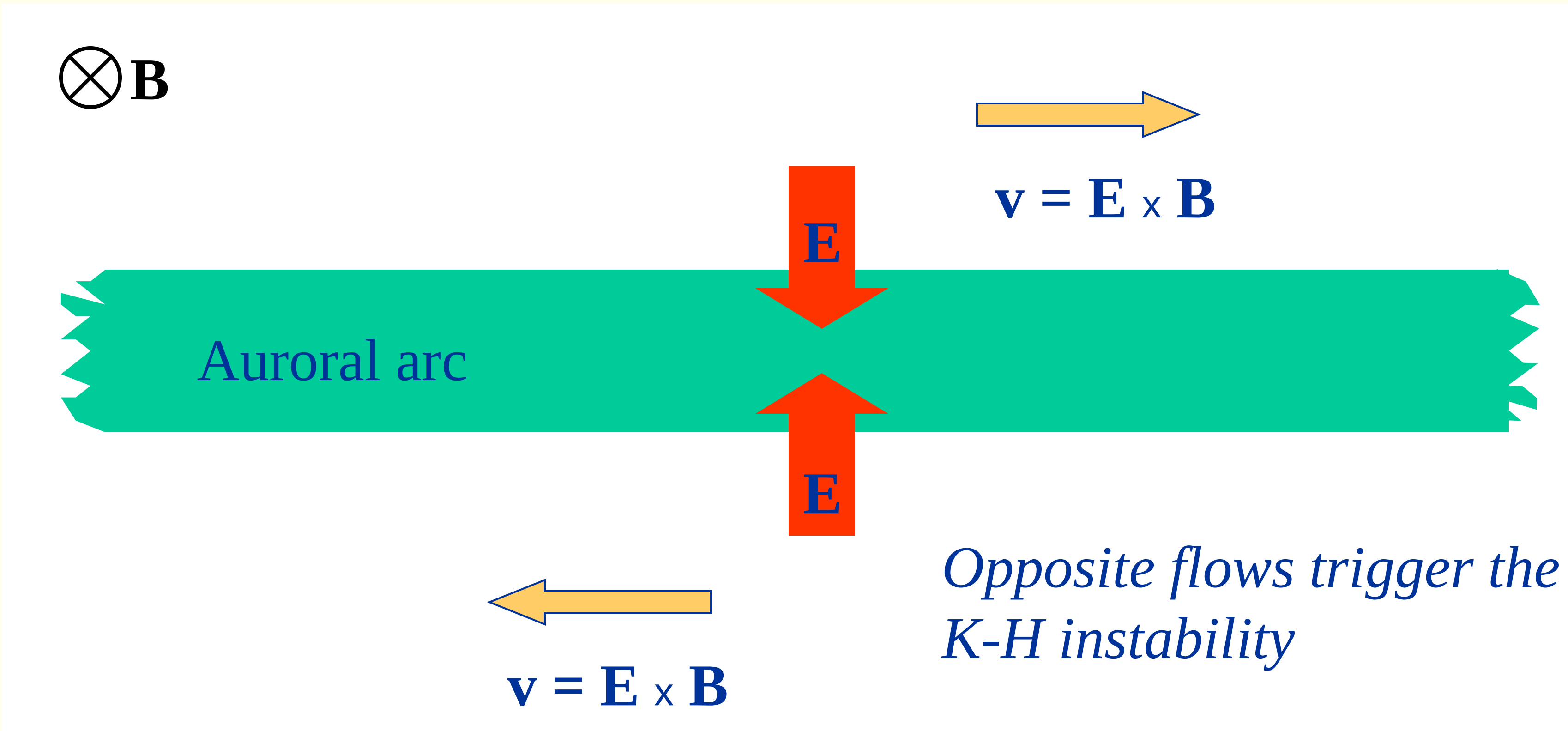
Satellite signatures of U potential



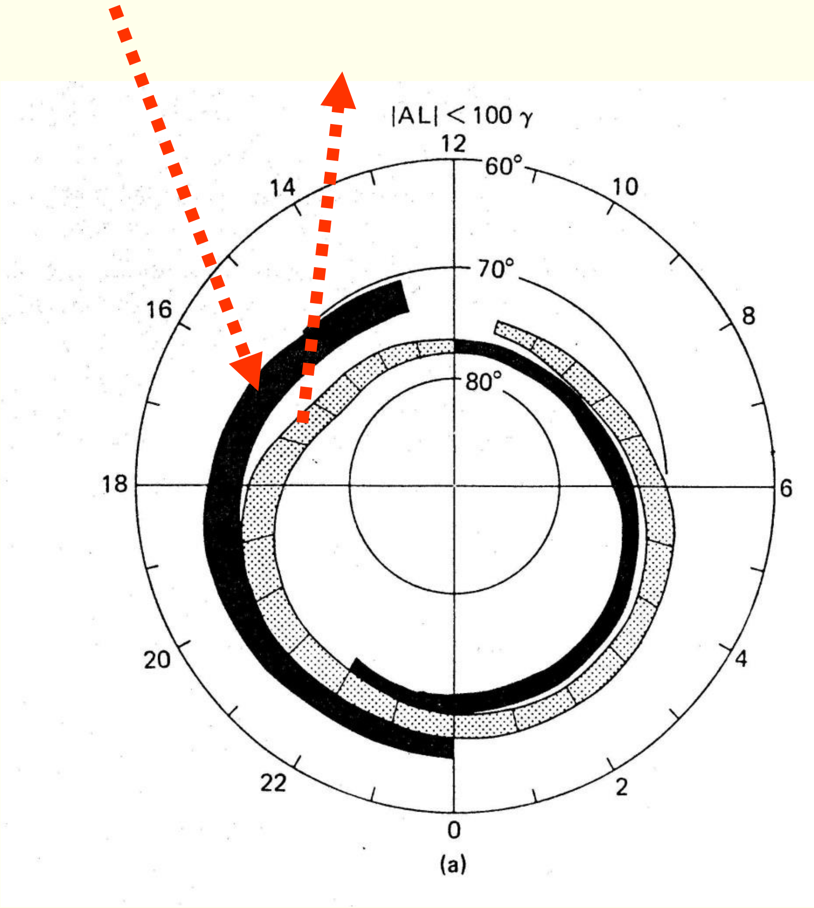


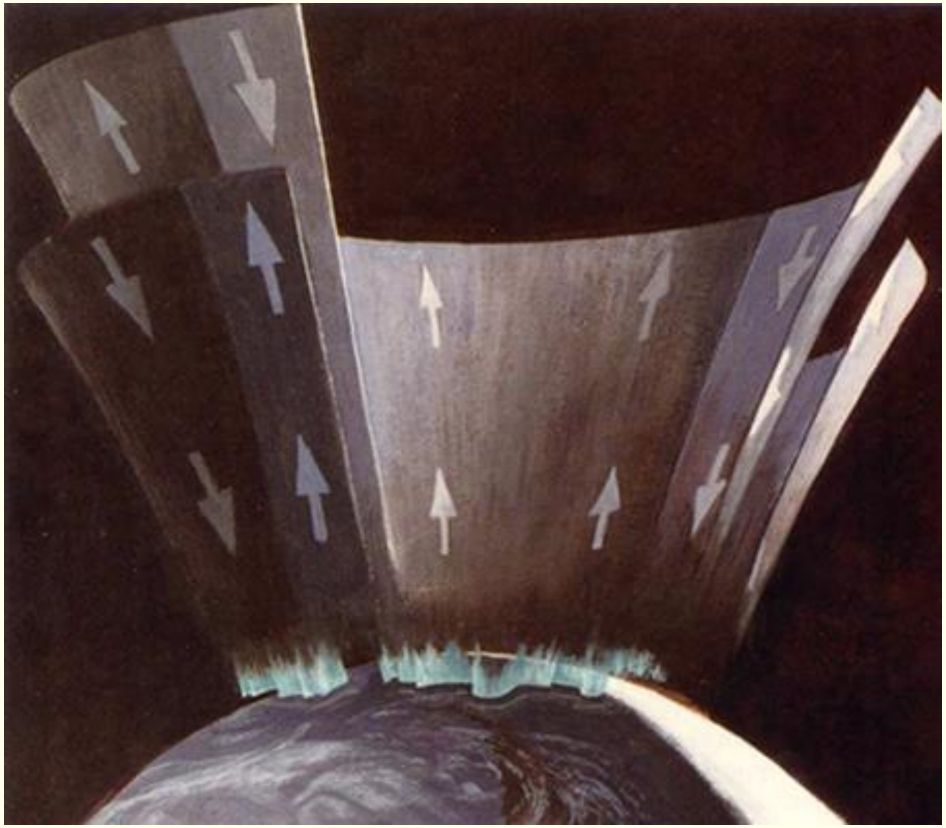
Measurements made by the ISEE satellite (Mozer et al., 1977)

Spirals – Kelvin-Helmholz instability

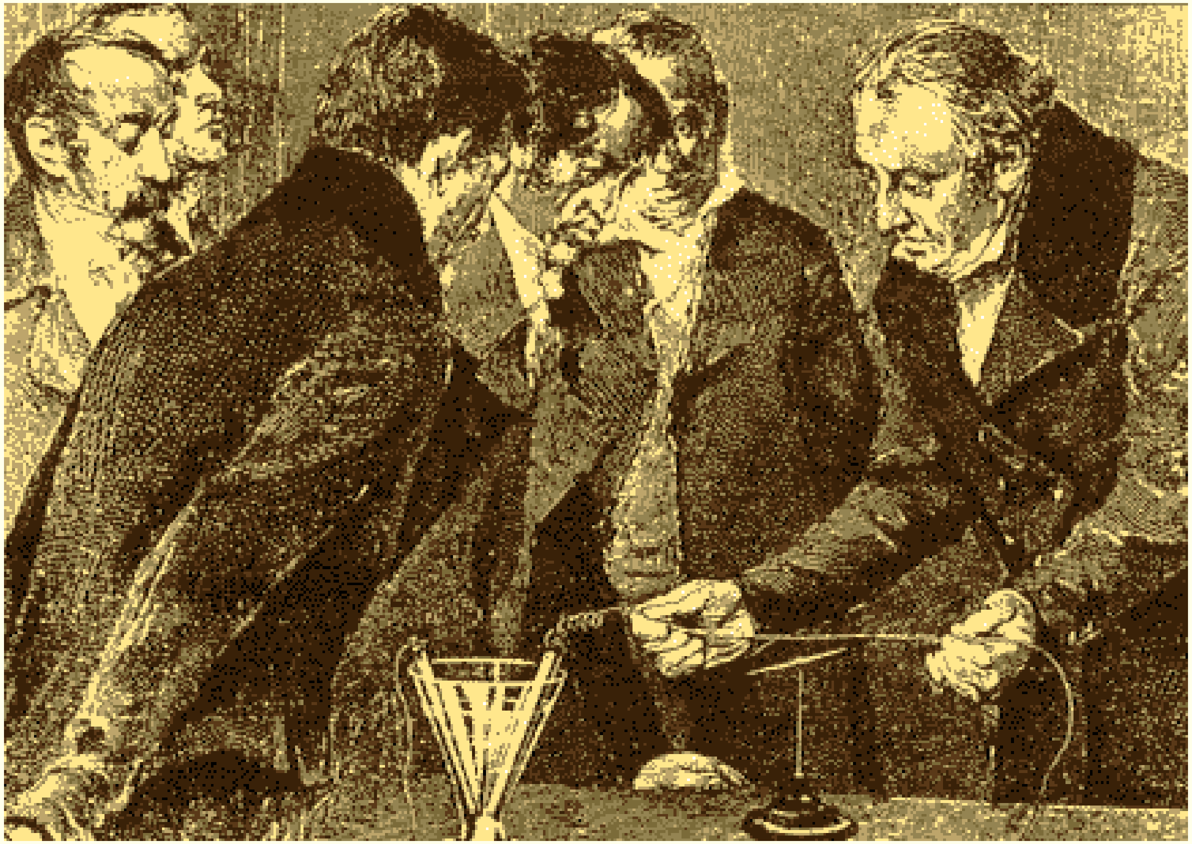


Birkeland currents in the auroral oval

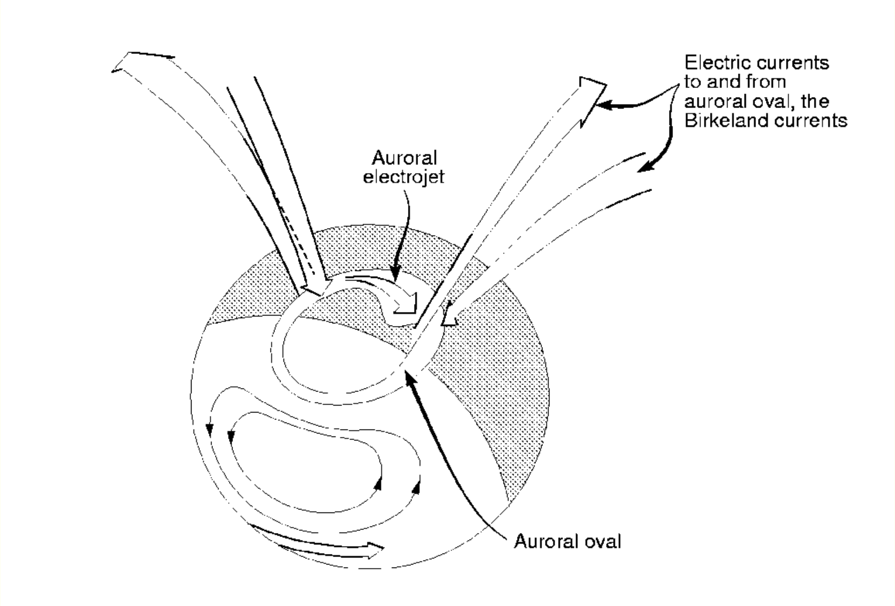




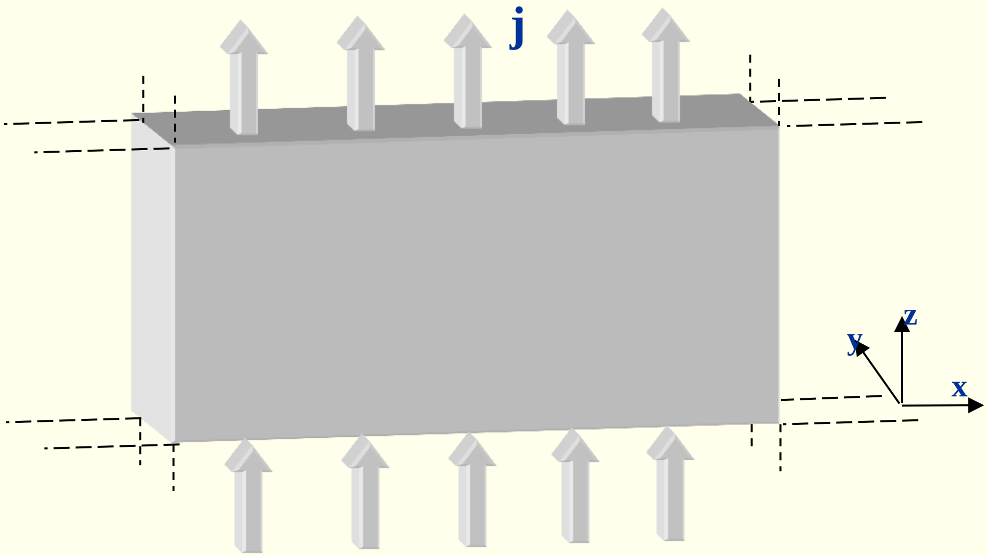
How can you measure currents in space?



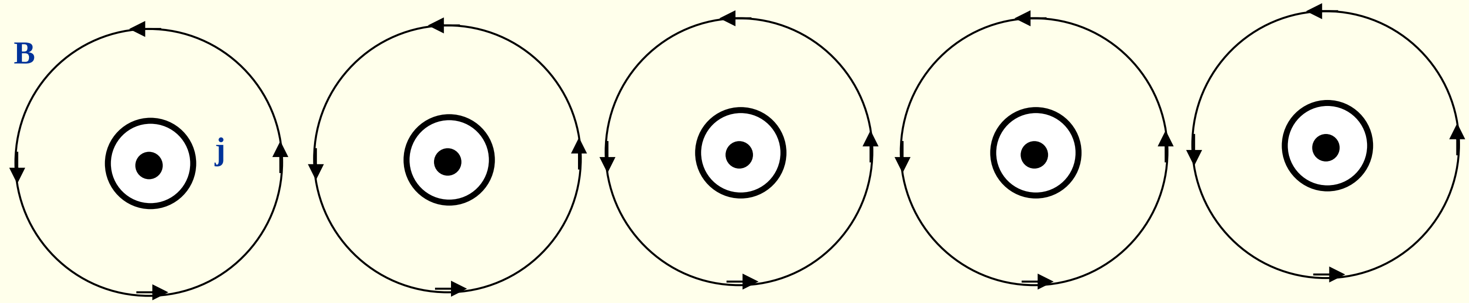
Current sheet approximation



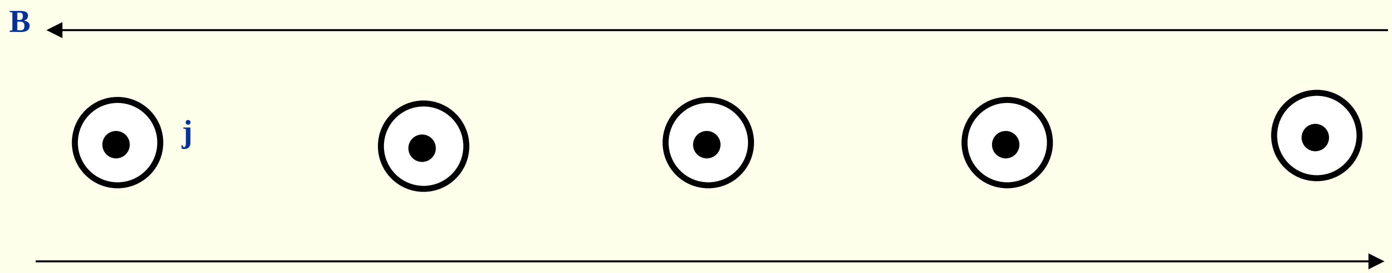
Approximate currents by thin current sheets with infinite size in the x- och z-directions.



Current sheet approximation



What will the magnetic field around such a current configuration be? Start by approximating with line currents to get a qualitative picture.



The closer you place the line currents, the more the magnetic fields between the line currents will cancel