Last lecture (7)

- Particle motion in magnetosphere
- Other magnetospheres

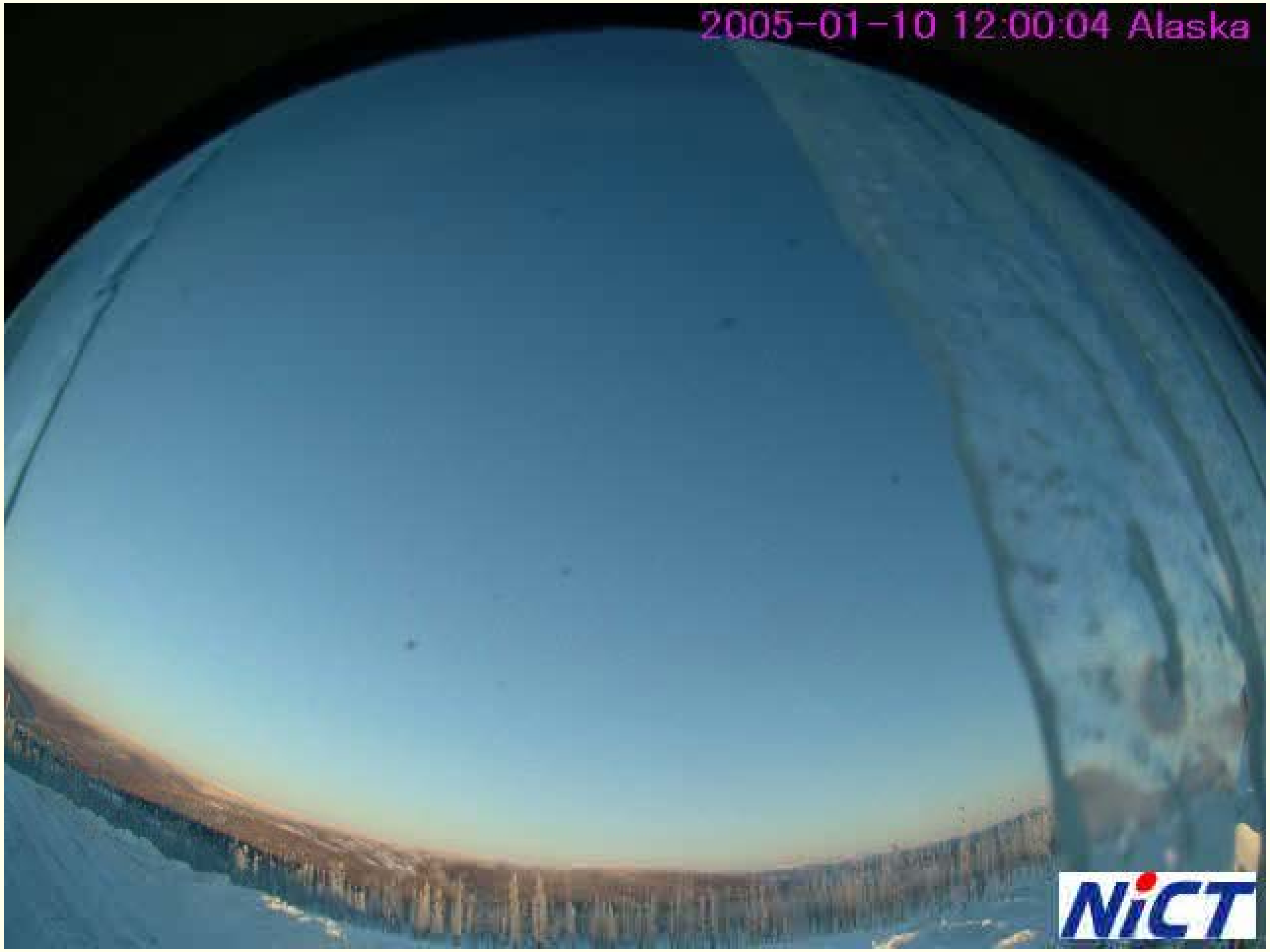
Today's lecture (8)

- Aurora
- How to measure currents in space
- Magnetospheric dynamics

Today

Activity	Date	Time	Room	Subject	Litterature
L1	29/8	13-15	E52	Course description, Introduction, The Sun 1, Plasma physics 1	**CGF** Ch 1, 5, (p 110-113)
L2	1/9	15-17	L52	The Sun 2, Plasma physics 2	**CGF** Ch 5 (p 114-121), 6.3
L3	5/9	13-15	E51	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	8/9	15-17	D41	Mini-group work 1	
L4	12/9	13-15	E35	The ionosphere 2, Plasma physics 4	**CGF** Ch 3.4, 3.7, 3.8
L5	14/9	10-12	V32	The Earth's magnetosphere 1, Plasma physics 5	**CGF** 4.1-4.3, **LL** Ch I, II, IV.A
T2	15/9	15-17	E51	Mini-group work 2	
L6	19/9	13-15	M33	The Earth's magnetosphere 2, Other magnetospheres	**CGF** Ch 4.6-4.9, **LL** Ch V.
T3	22/9	15-17	E51	Mini-group work 3	
L7	26/9	13-15	E31	Aurora, Measurement methods in space plasmas and data analysis 1	**CGF** Ch 4.5, 10, **LL** Ch VI, Extra material
L8	28/9	10-12	L52	Space weather and geomagnetic storms	**CGF** Ch 4.4, **LL** Ch IV.B-C, VII.A-C
T4	29/9	15-17	M31	Mini-group work 4	
L9	3/10	13-15	E52	Interstellar and intergalactic plasma, Cosmic radiation,	**CGF** Ch 7-9
T5	6/10	15-17	E31	Mini-group work 5	
L10	10/10	13-15	E52	Swedish and international space physics research.	
T6	13/10	15-17	E31	Round-up, old exams.	
Written exami-nation	26/10	8-13	F2		

The aurora

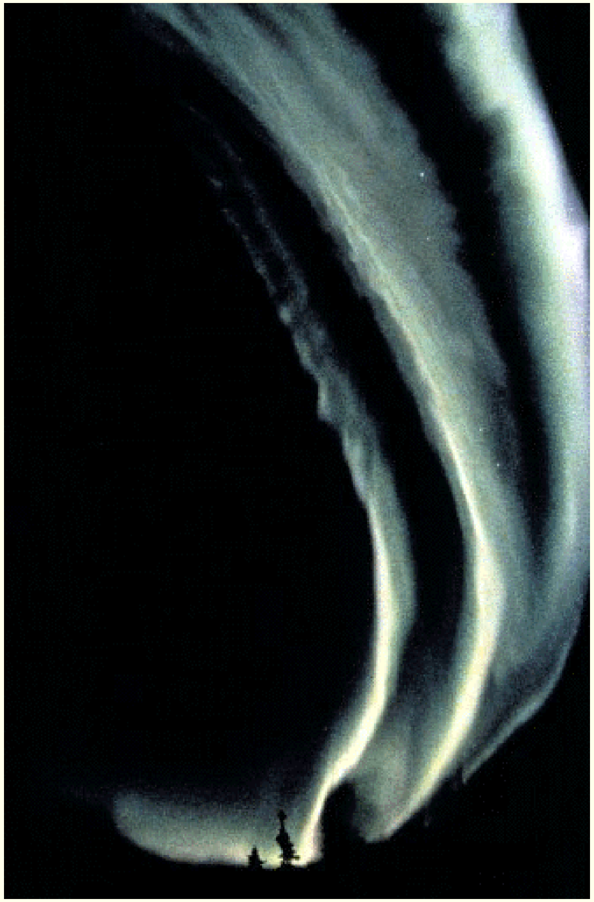


The aurora

The aurora

The aurora

Homogenous auroral arcs

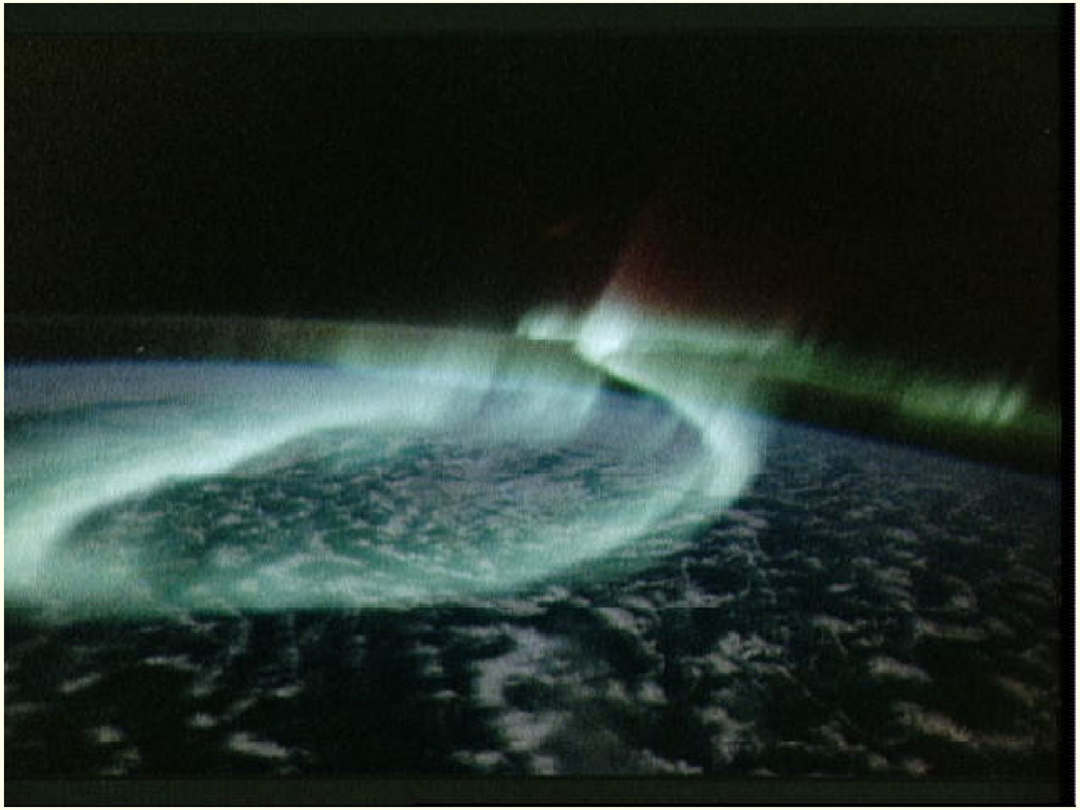


Rays, curtains

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

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

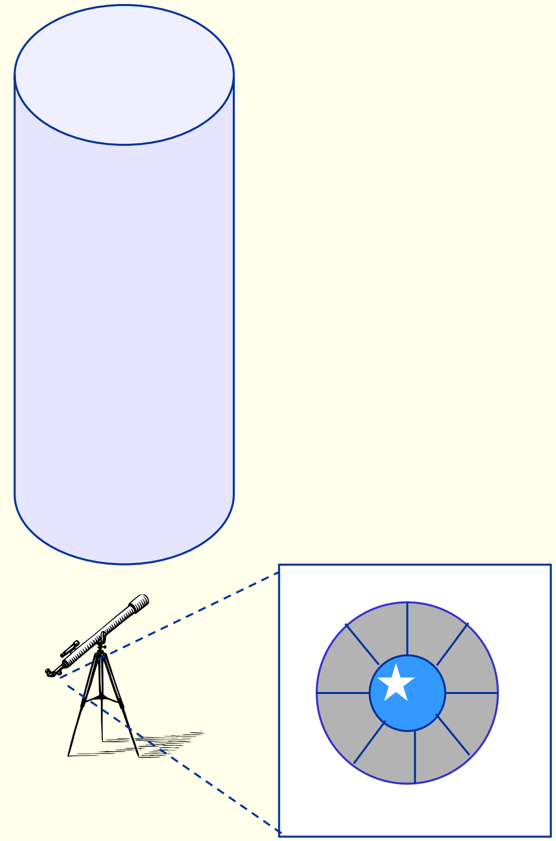
Auroral spirals



Develop when arcs become unstable

Auroral corona

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



Aurora - altitude

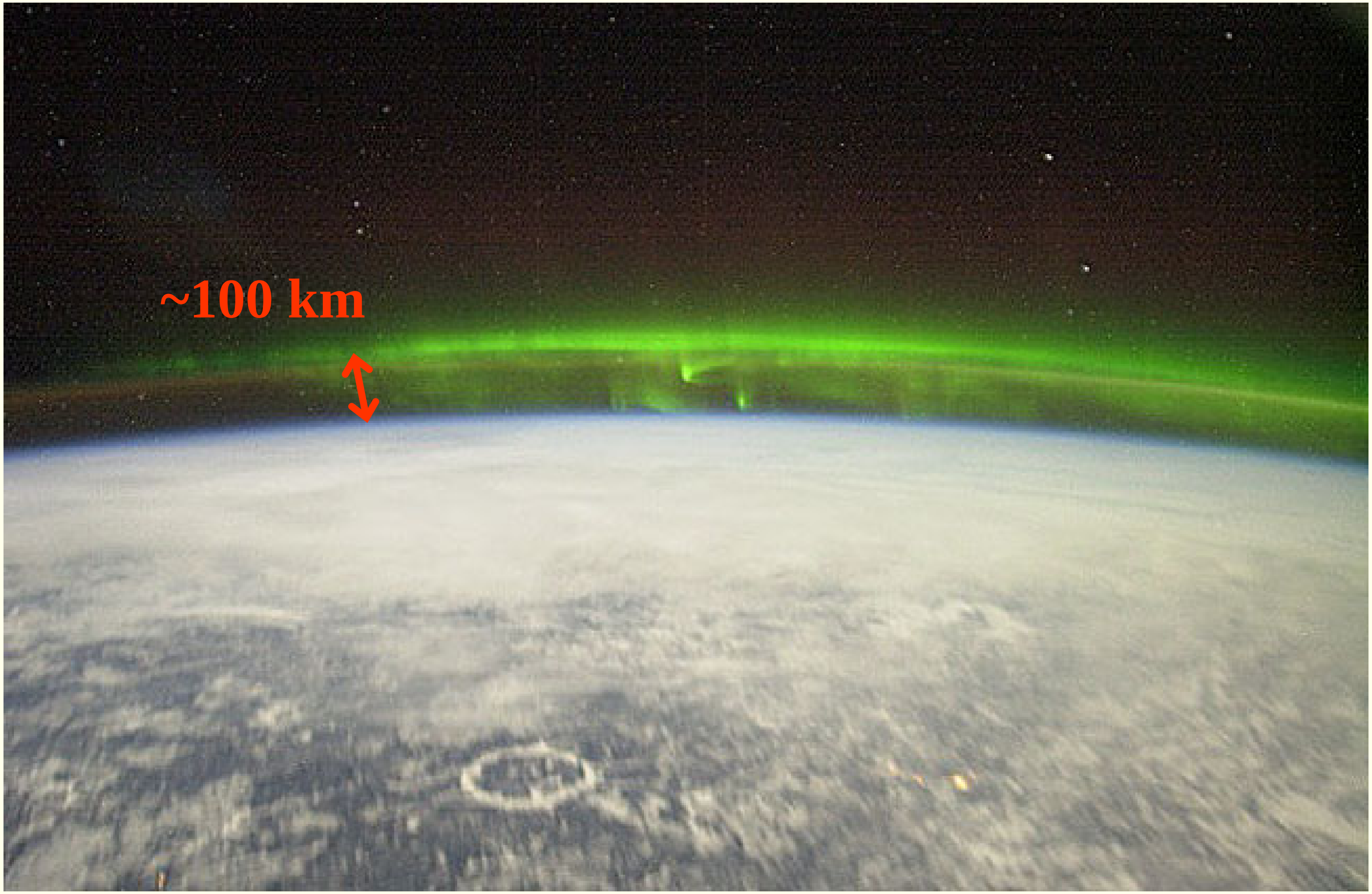


Foto from International Space Station

Early notions

Woodcut from Böhmen 1570.

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

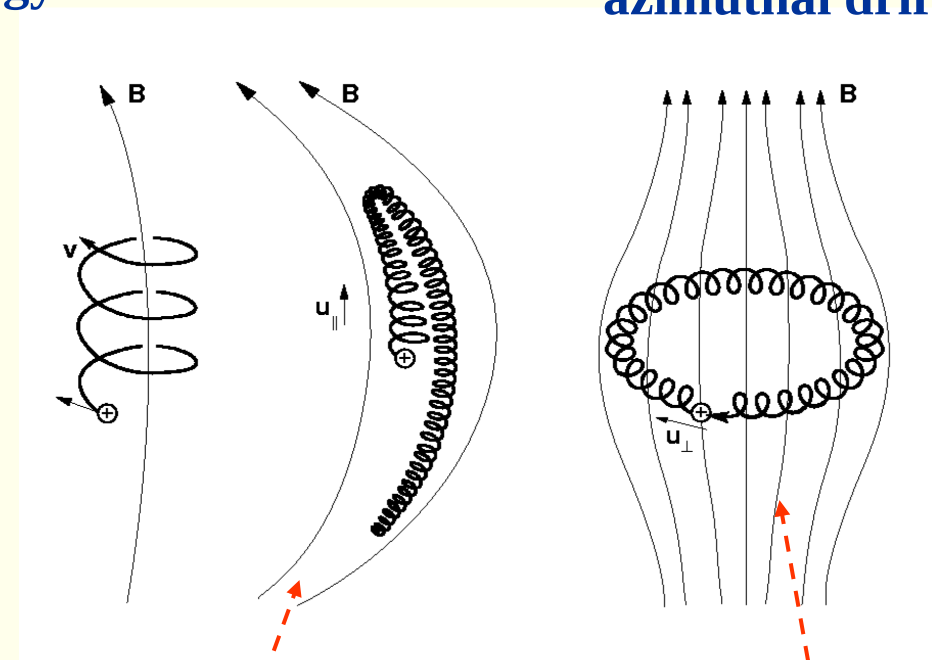
What causes the aurora?

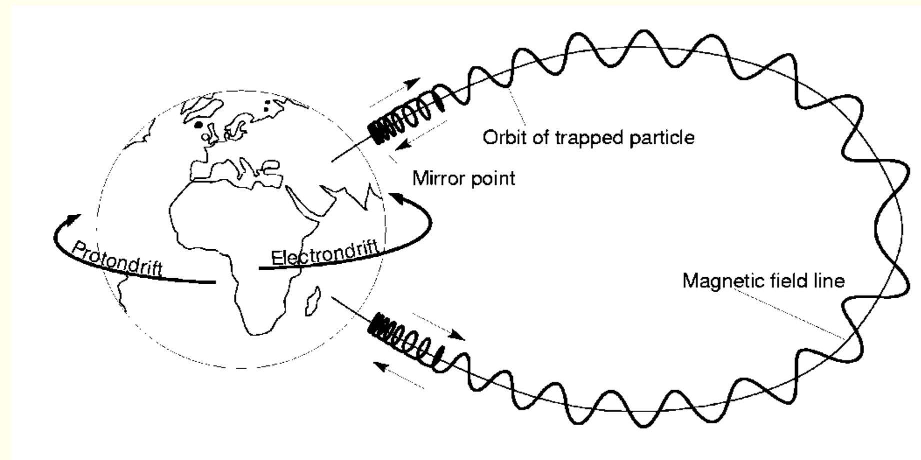
Particle motion in geomagnetic field

longitudinal oscillation

gyration

azimuthal drift

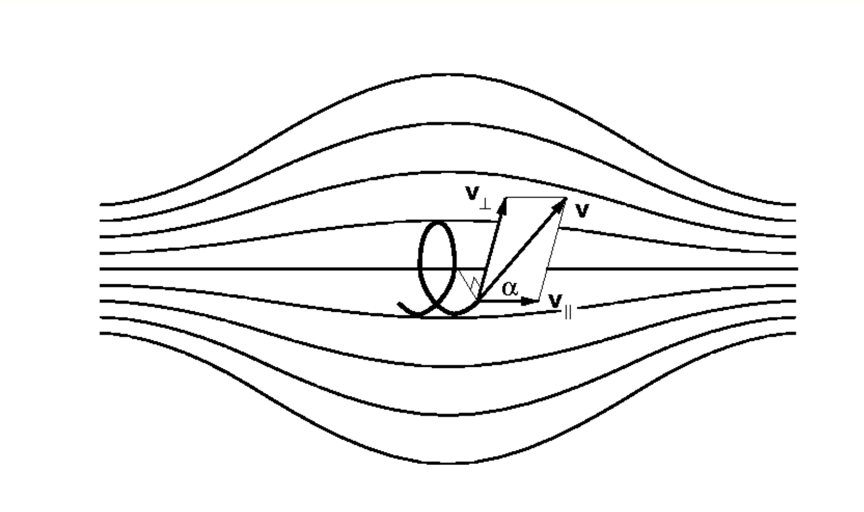




Magnetic mirror

grad B drift

Magnetic mirror



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

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

particle turns when $\alpha = 90°$ ➡

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

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

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

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

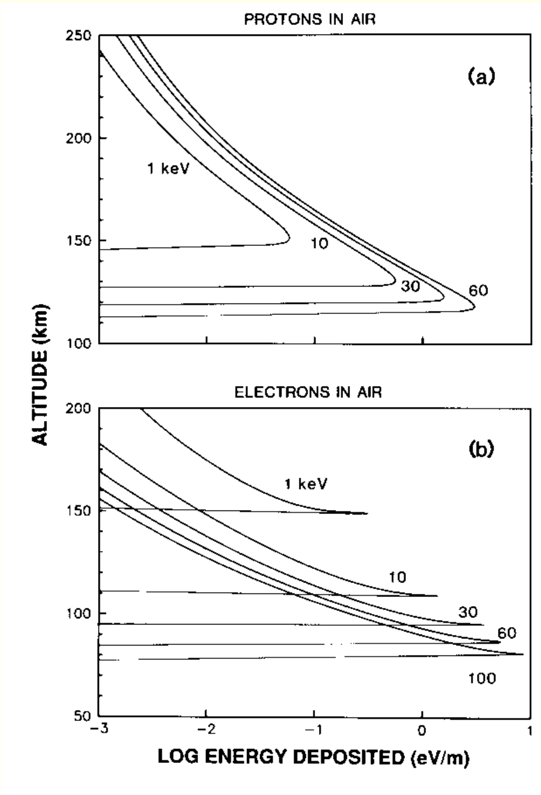
Particles in ***loss cone*** :

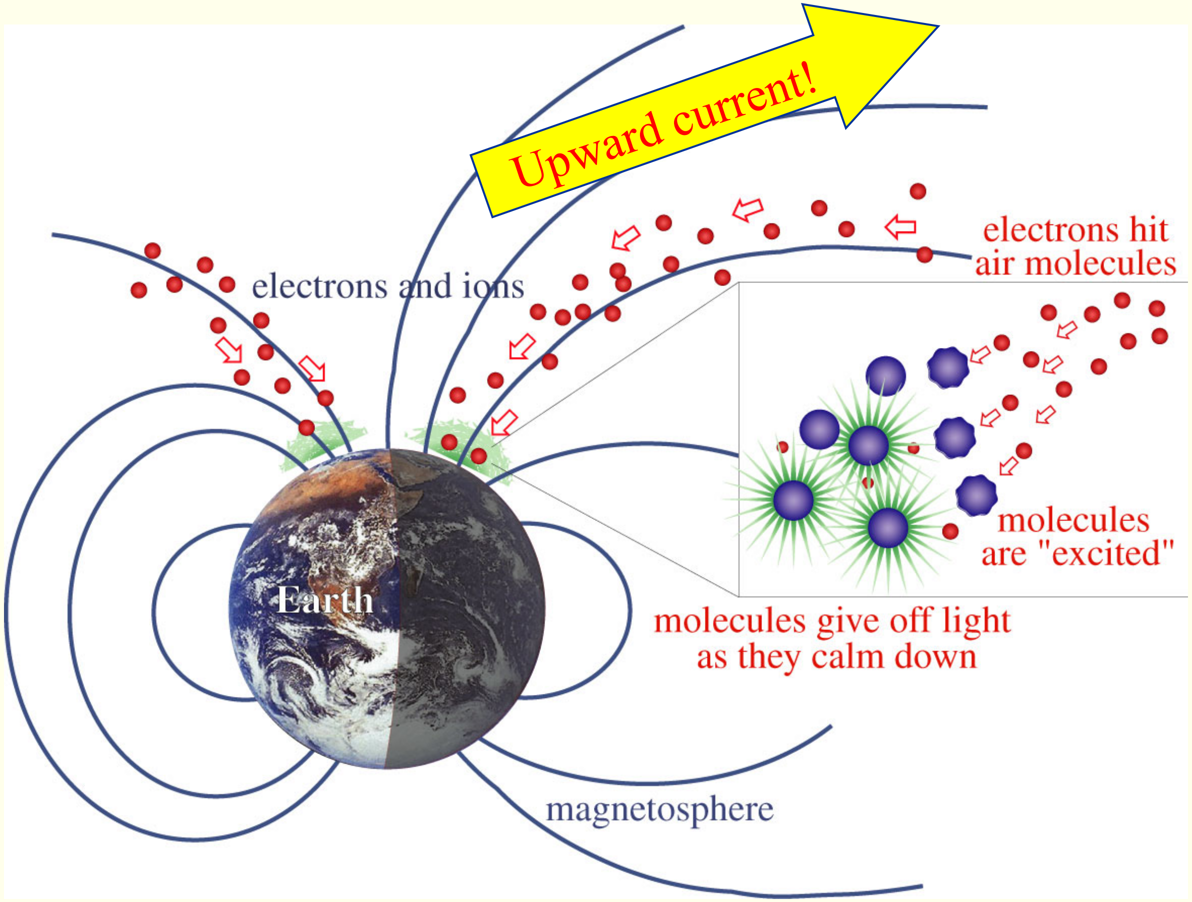
$$\alpha < \alpha_{lc}$$

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

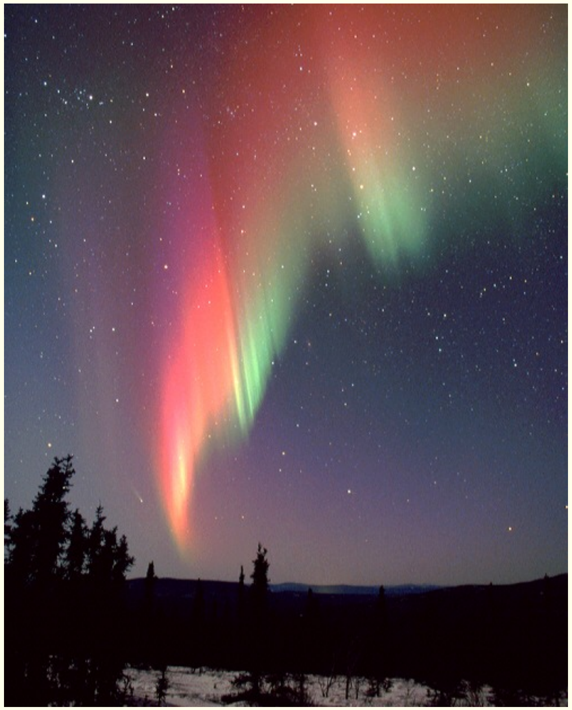
$$\mu = \frac{mv_\perp^2}{2B} = \frac{mv^2\sin^2\alpha}{2B}$$

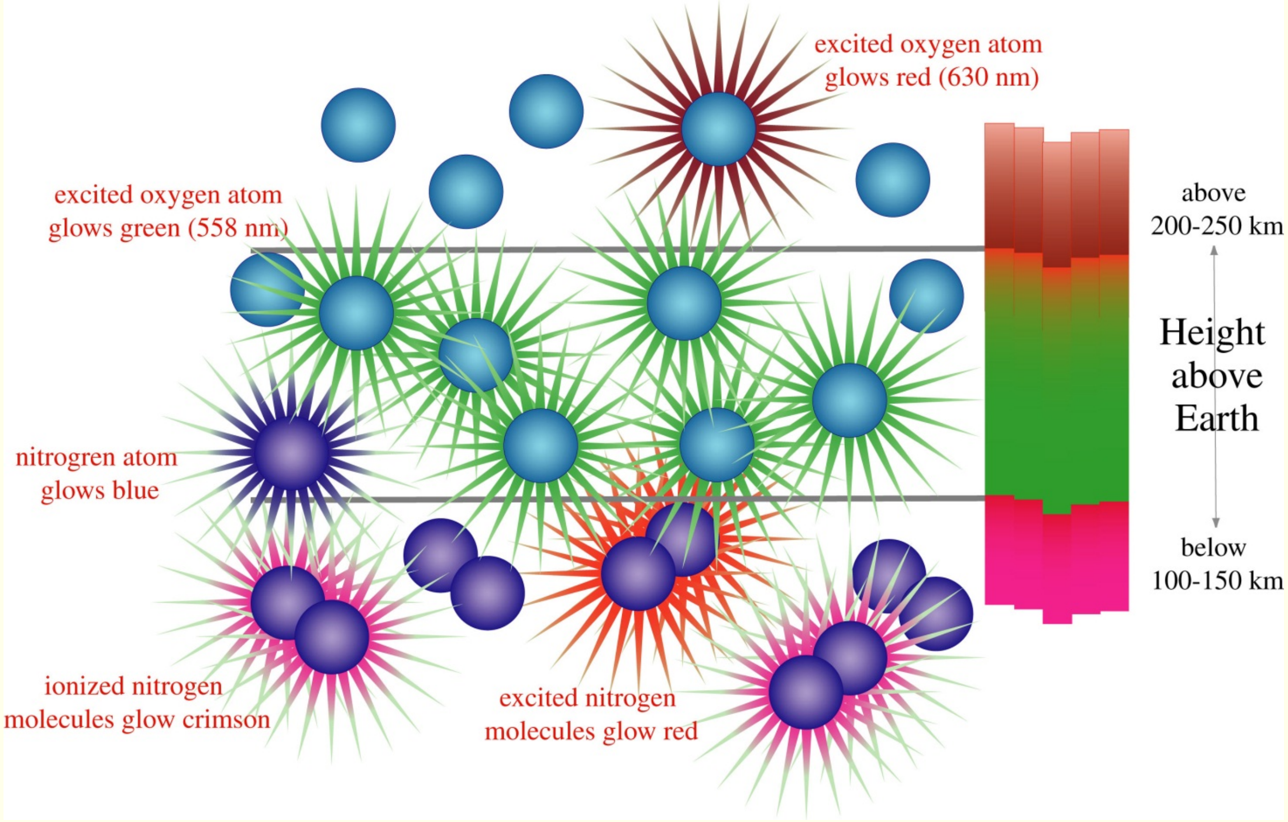
Collisions - emissions





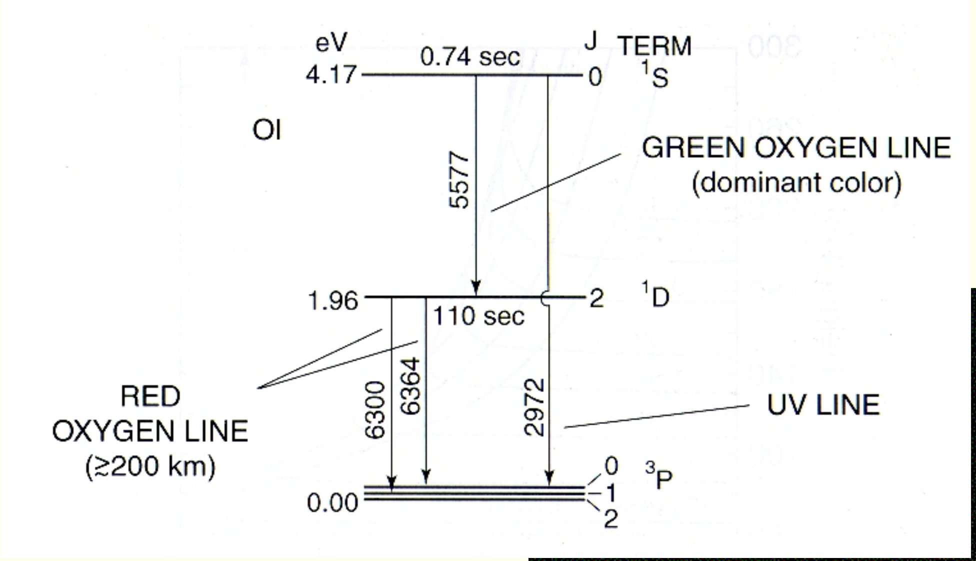
Emissions

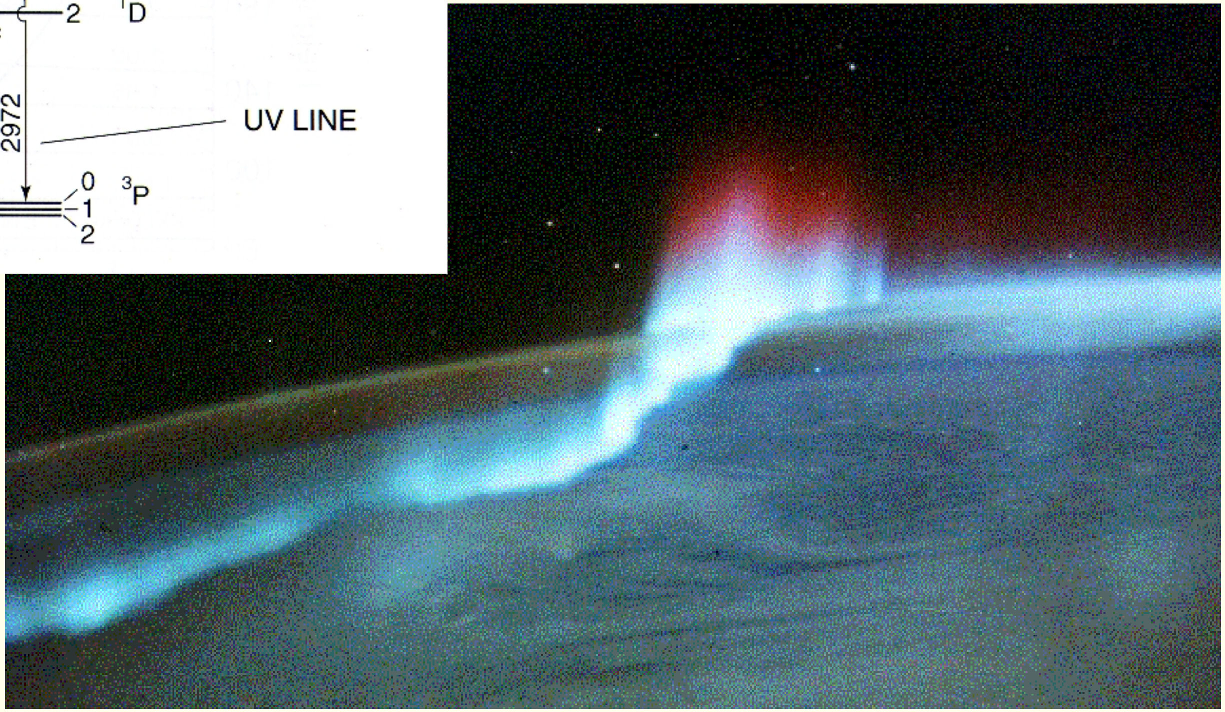




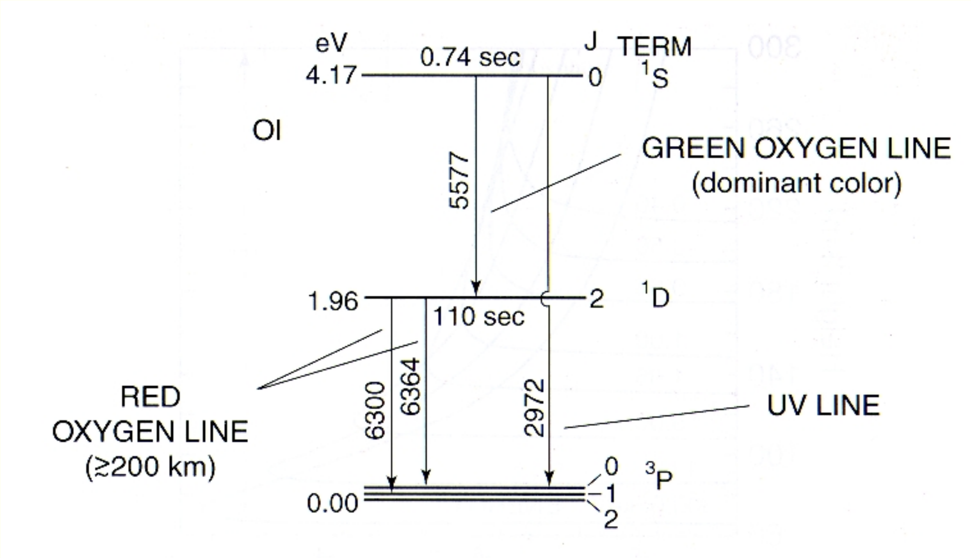
excited oxygen atom
glows red (630 nm)
excited oxygen atom
glows green (558 nm)
nitrogren atom
glows blue
ionized nitrogen
molecules glow crimson
excited nitrogen
molecules glow red
above
200-250 km
Height
above
Earth
below
100-150 km

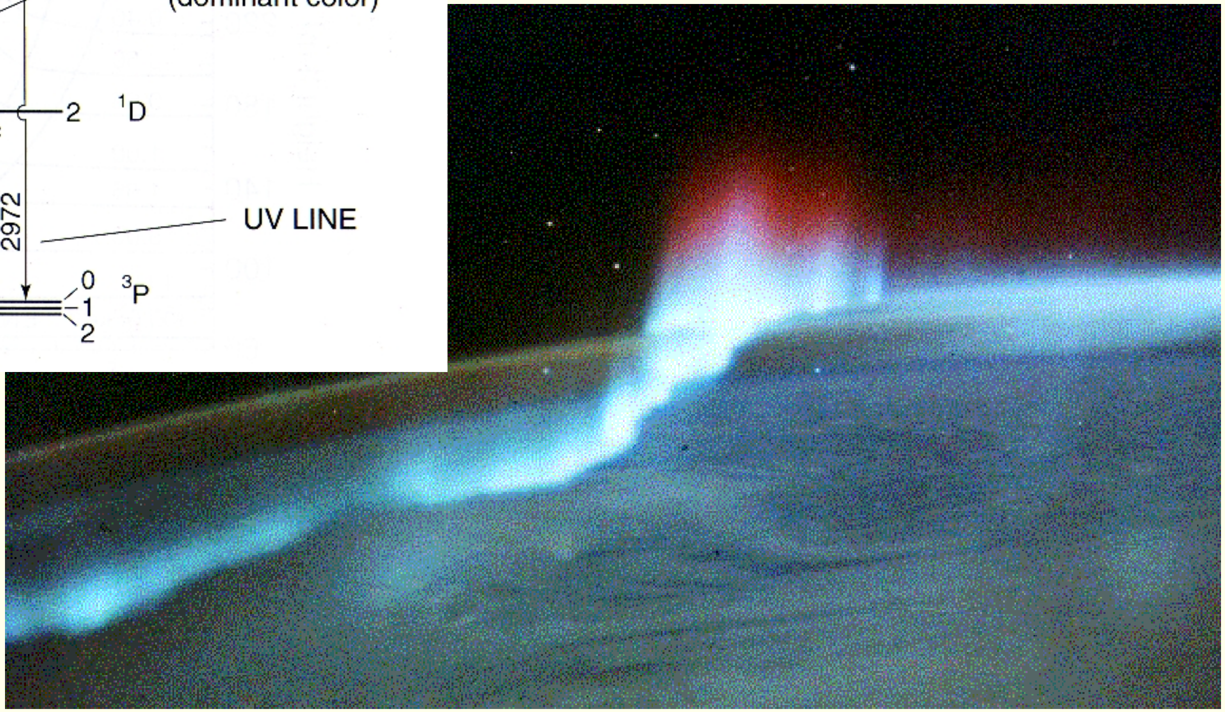
Oxygen emissions



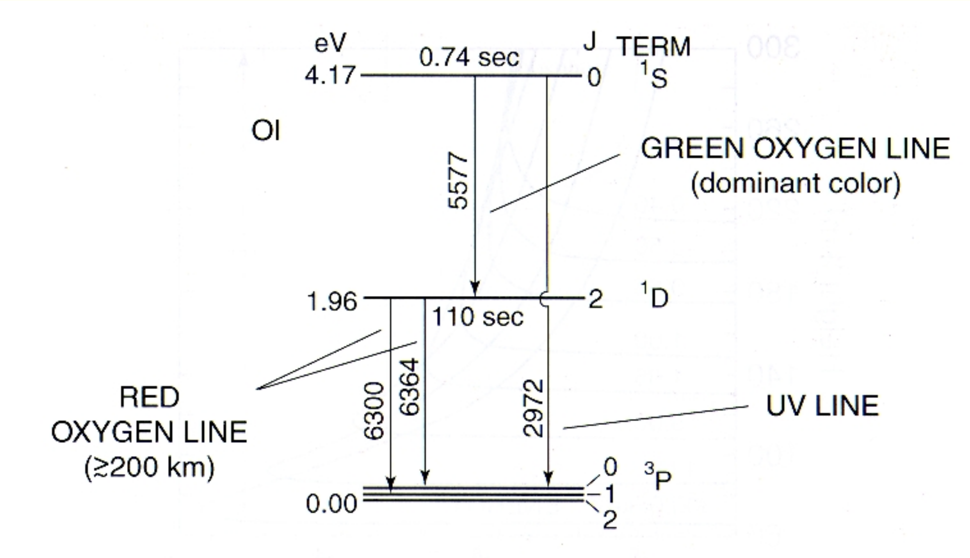


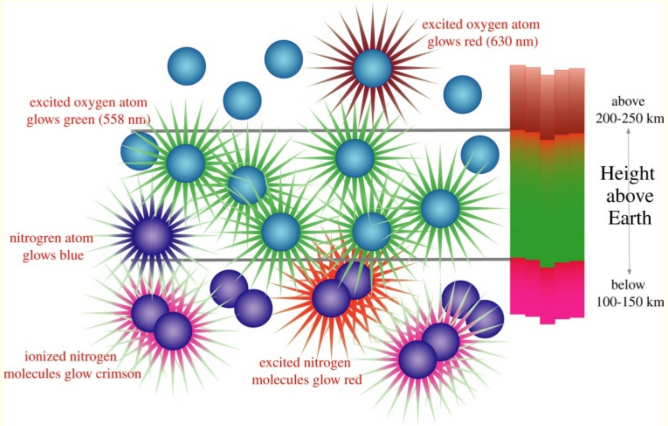
Why is there no red emissions at lower altitude?



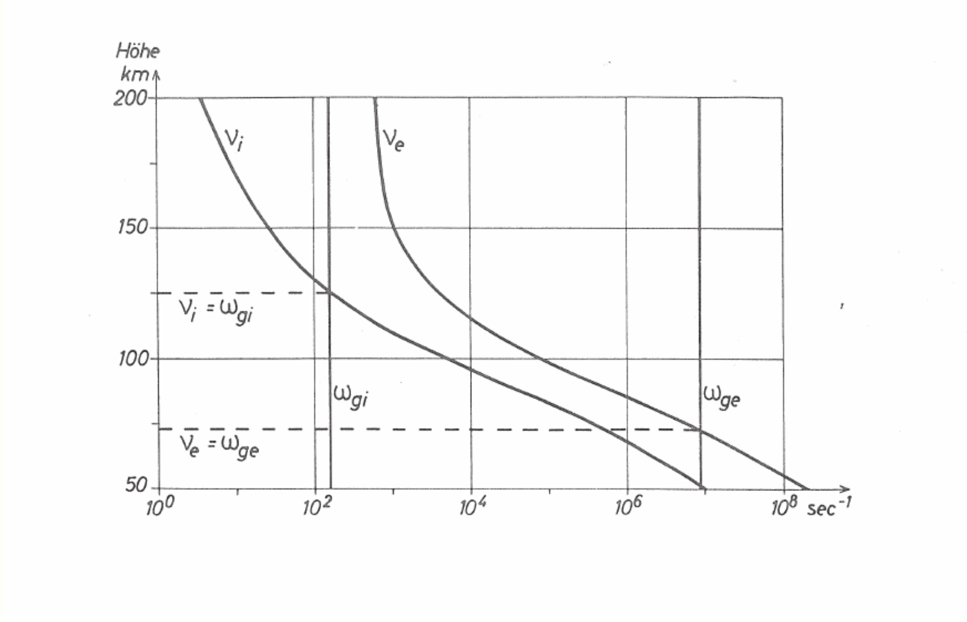


Oxygen emissions





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

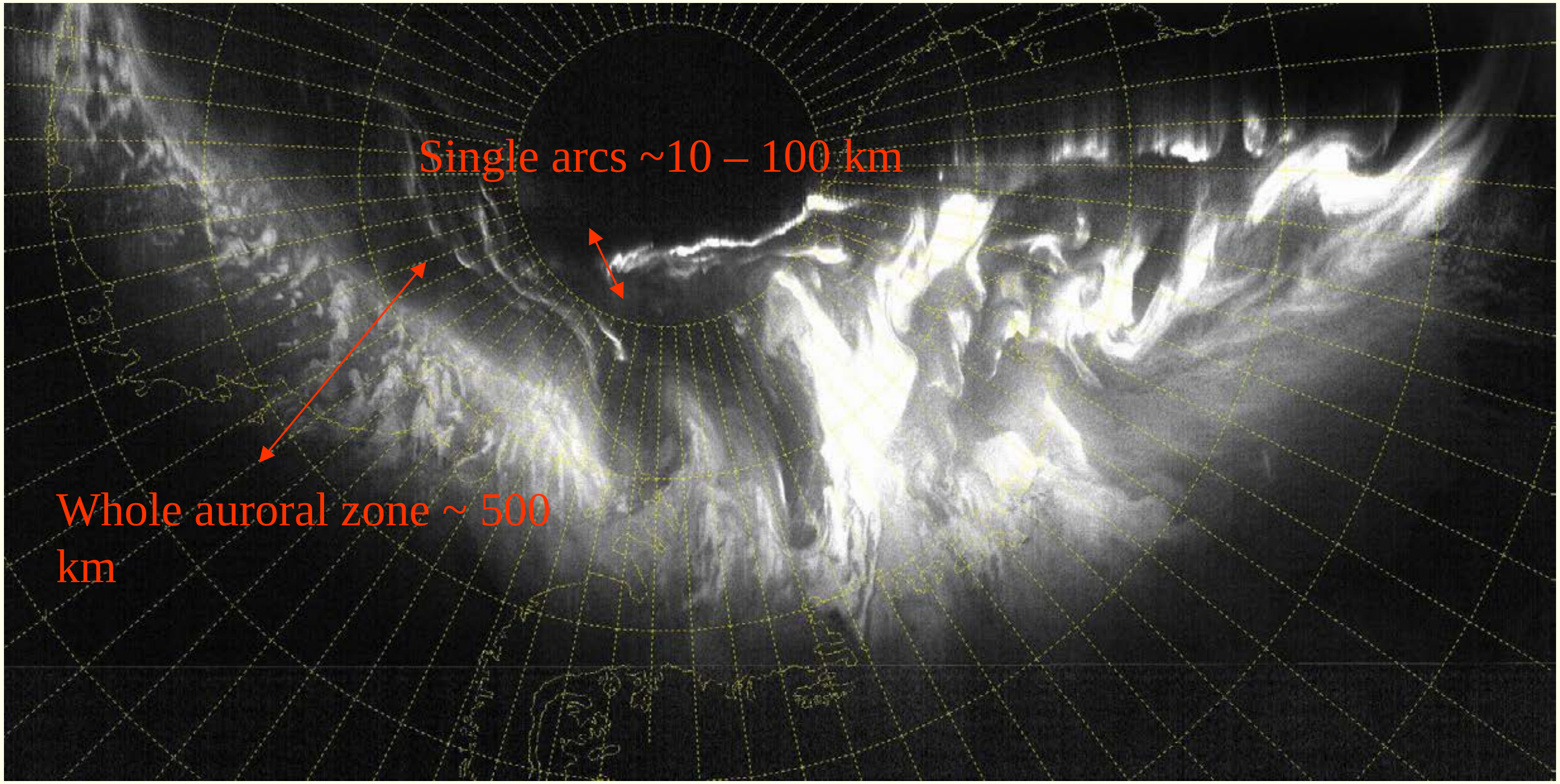
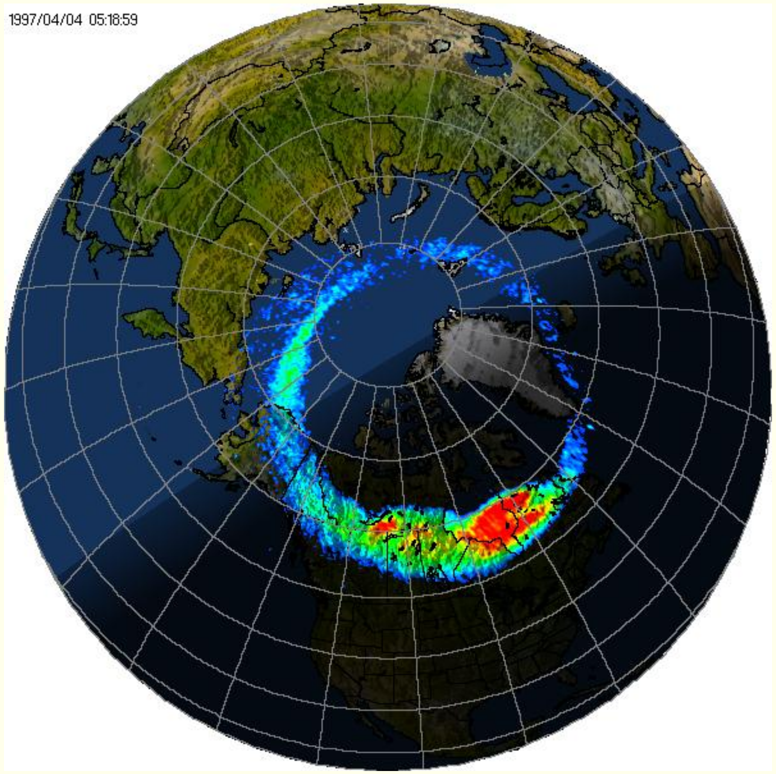
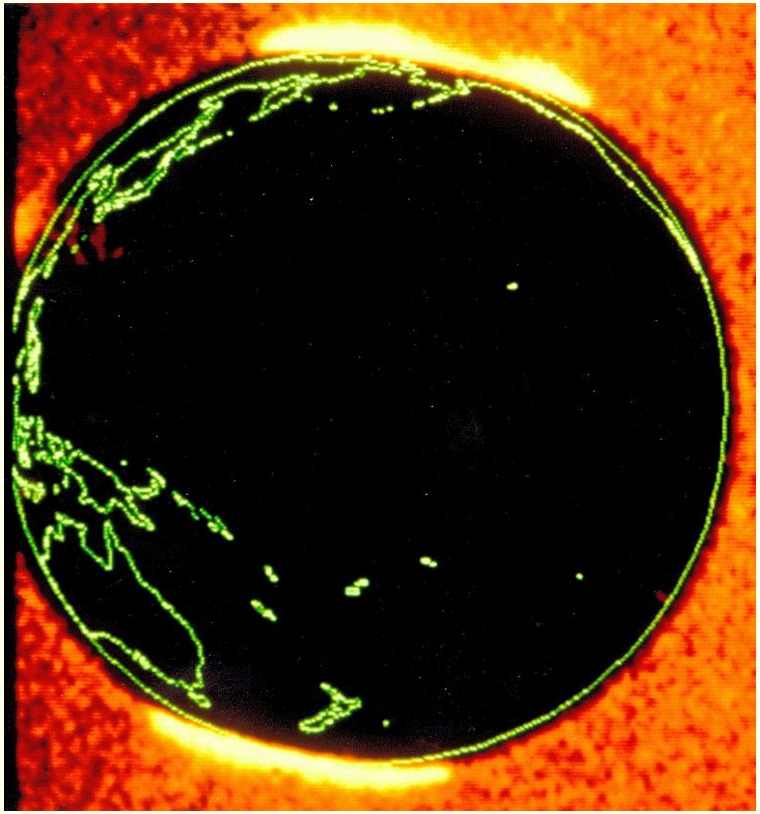


Foto från DMSP-satelliten

Auroral ovals



Polar

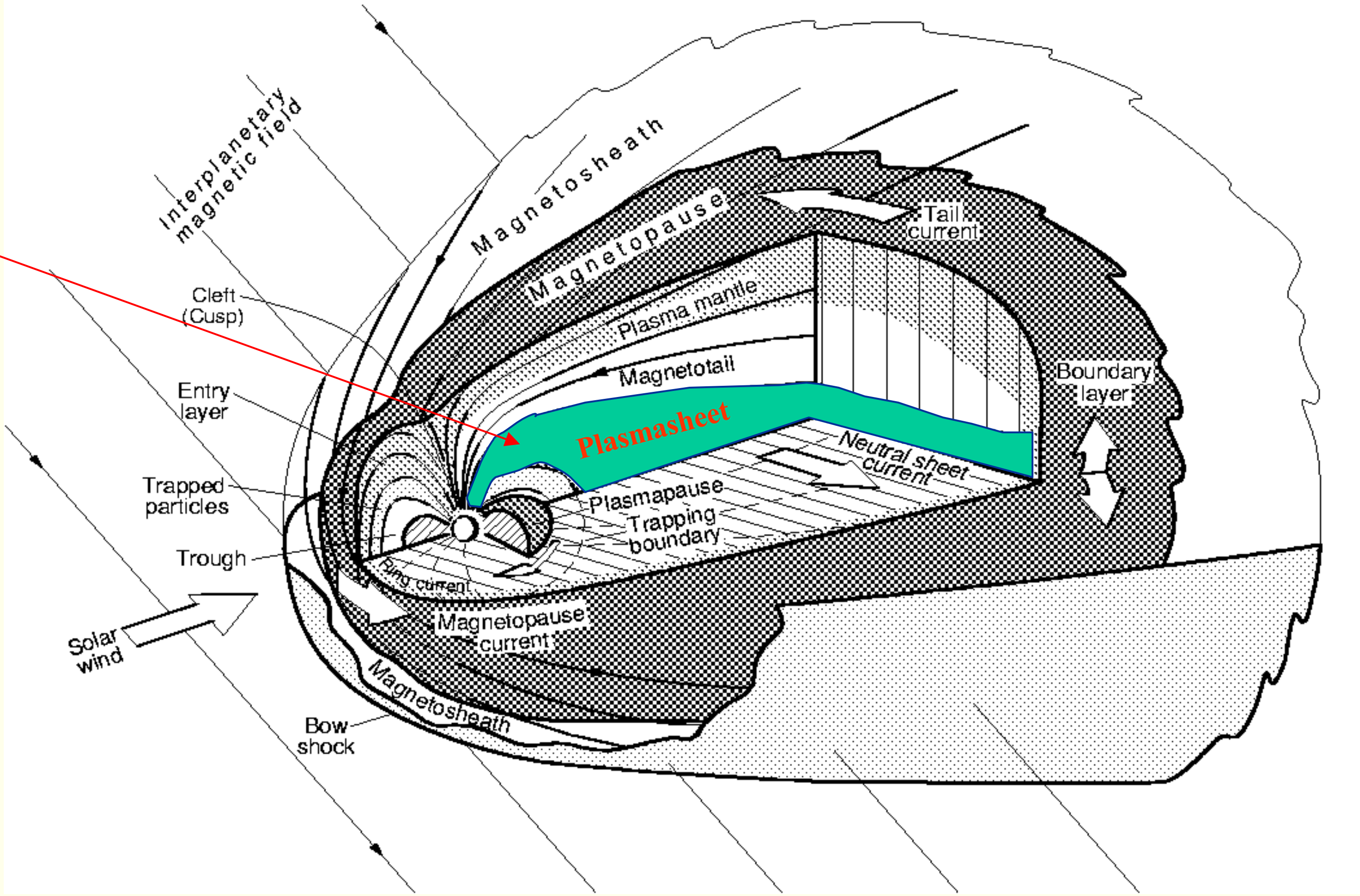


Dynamics Explorer

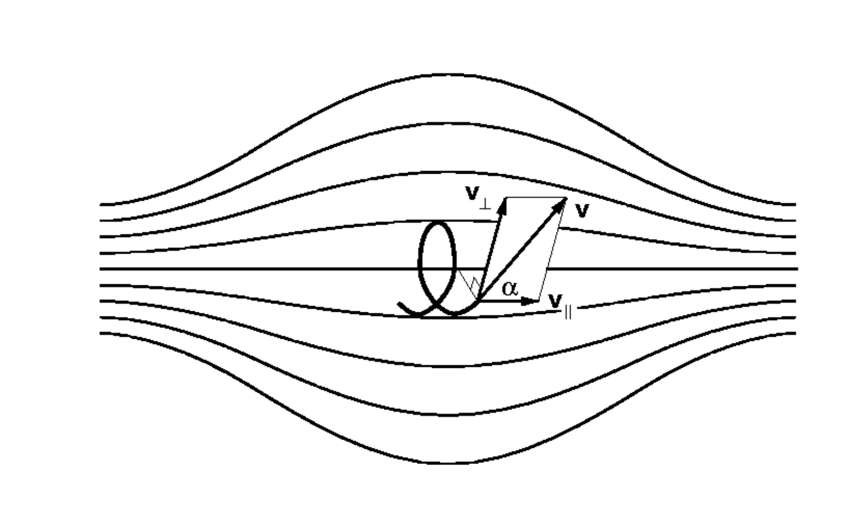
The auroral oval is the projection of the plasmasheet onto the atmosphere

Mystery!

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



Magnetic mirror



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

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Particles in ***loss cone*** :

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

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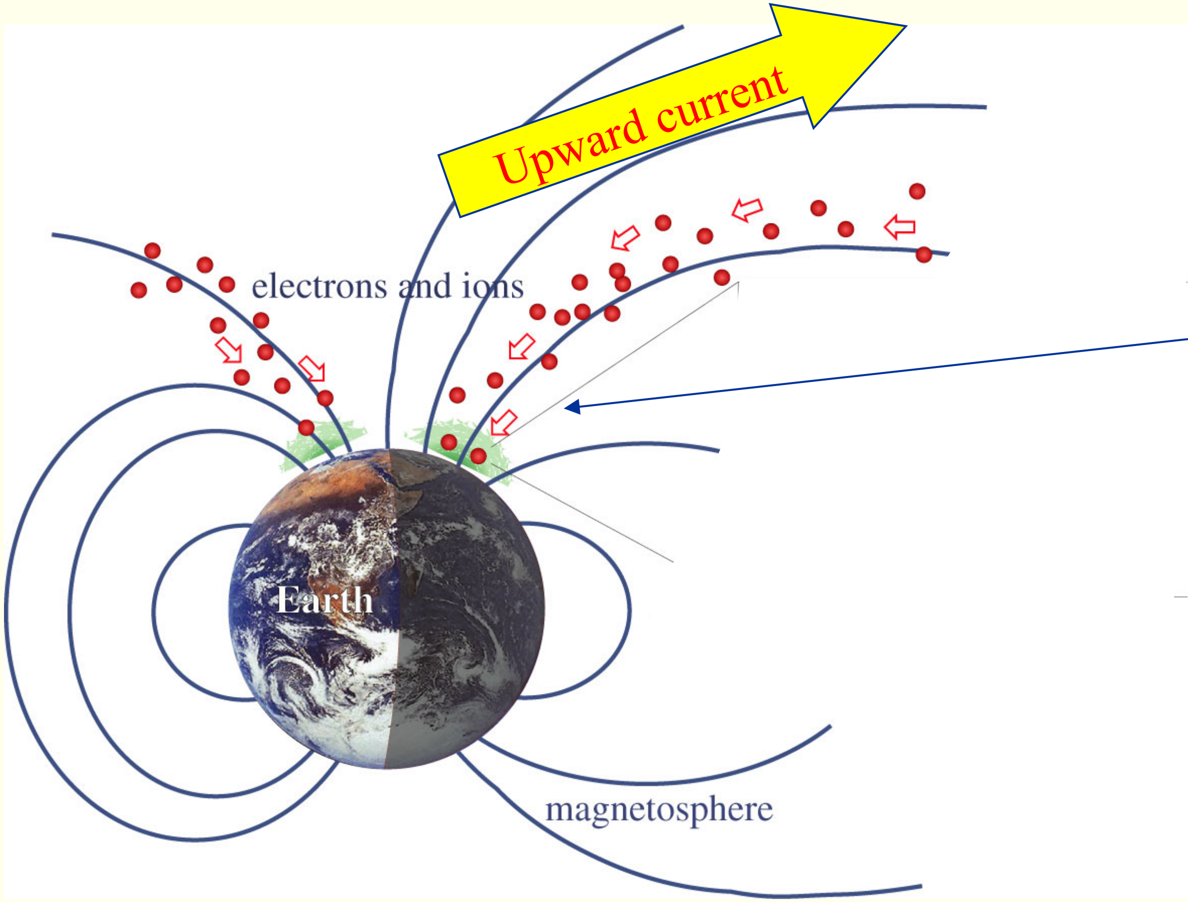
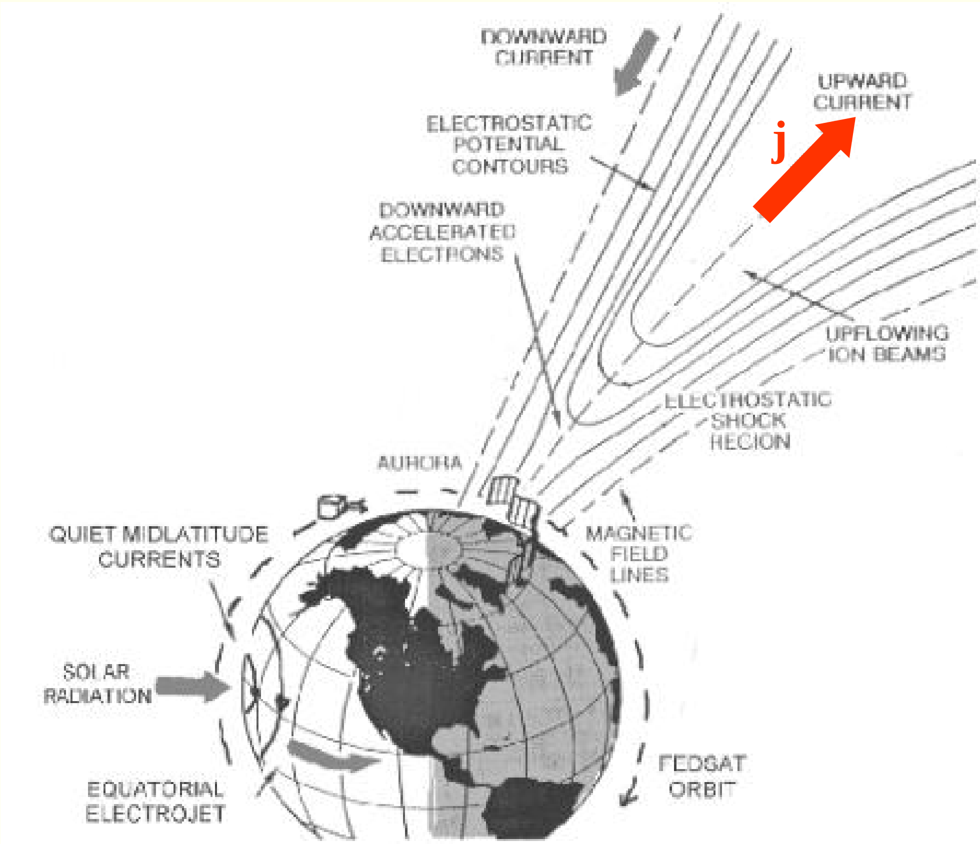
Why particle acceleration?



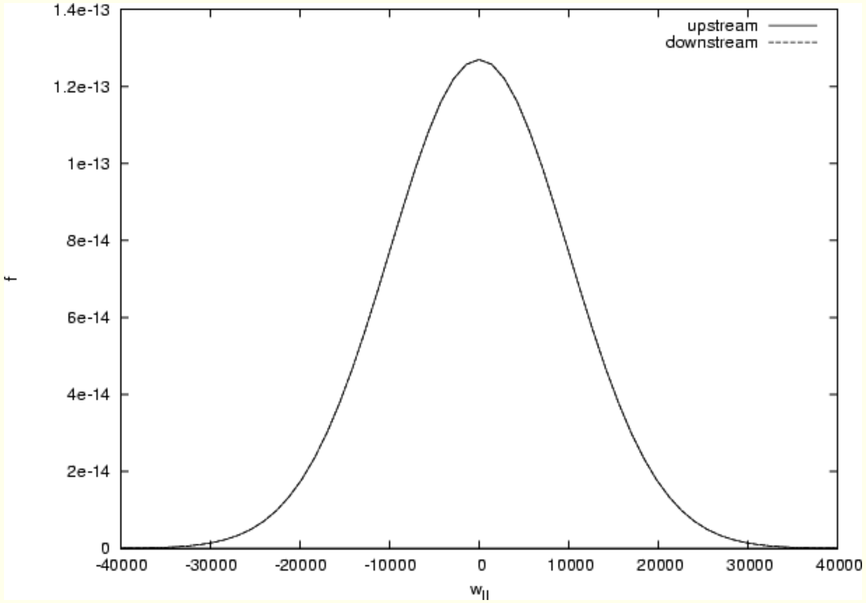
- The magnetosphere often seems to act as a current generator.
- The lower down you are on the field line, the more particles have been reflected by the magnetic mirror.
- At low altitudes there are not enough electrons to carry the current.

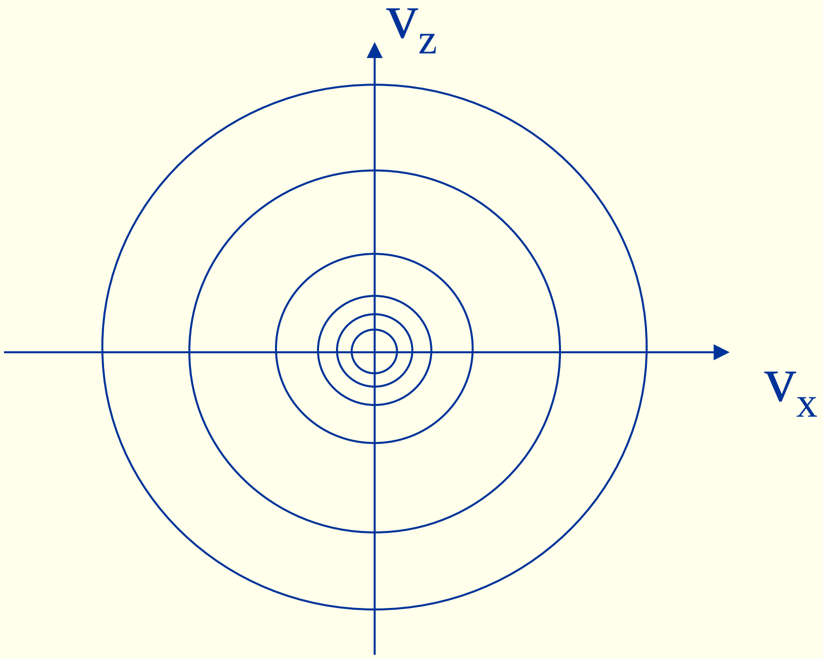
Why particle acceleration?



- 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

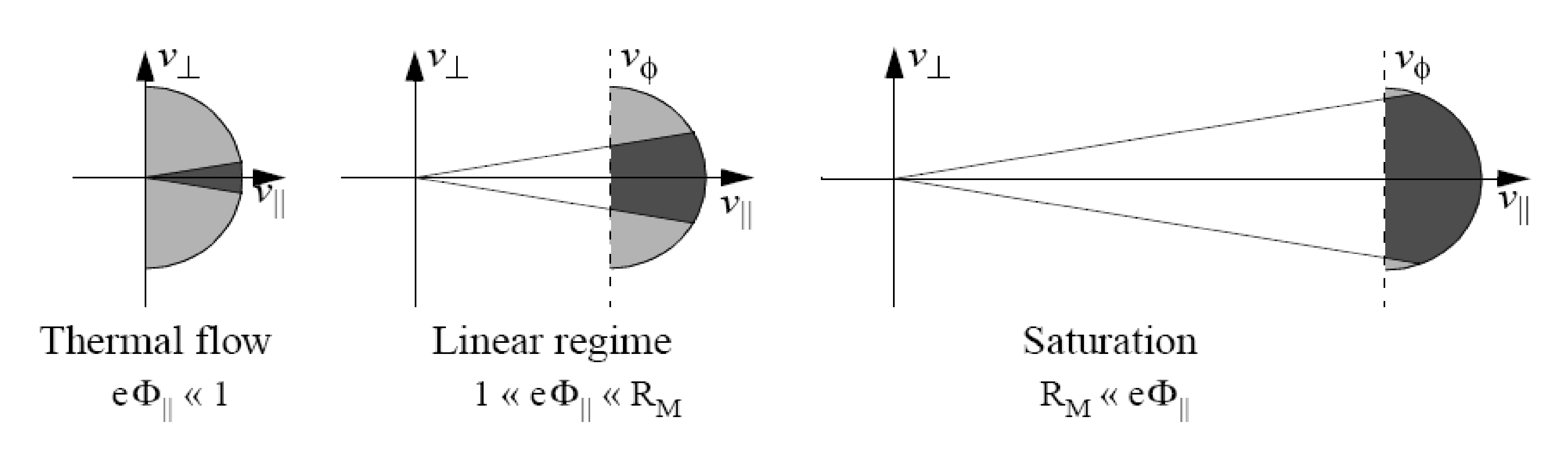




Example:
Maxwellian distribution

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

Why particle acceleration?



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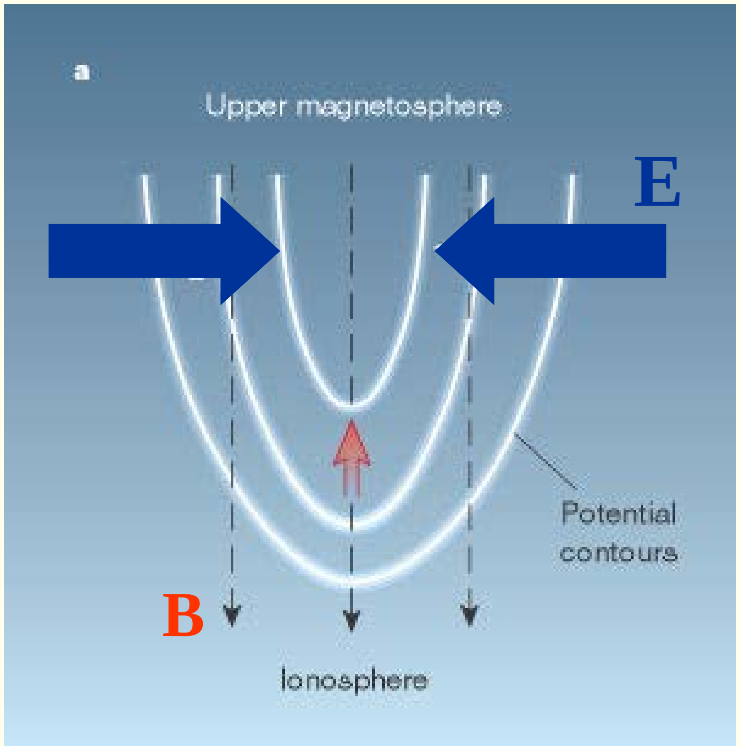
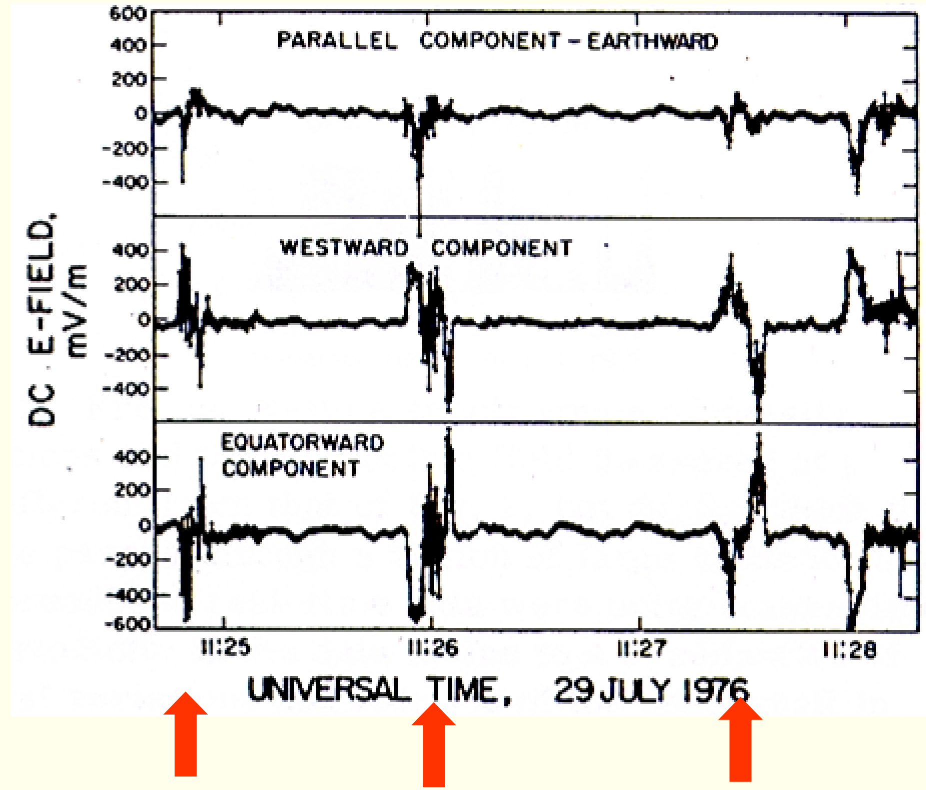
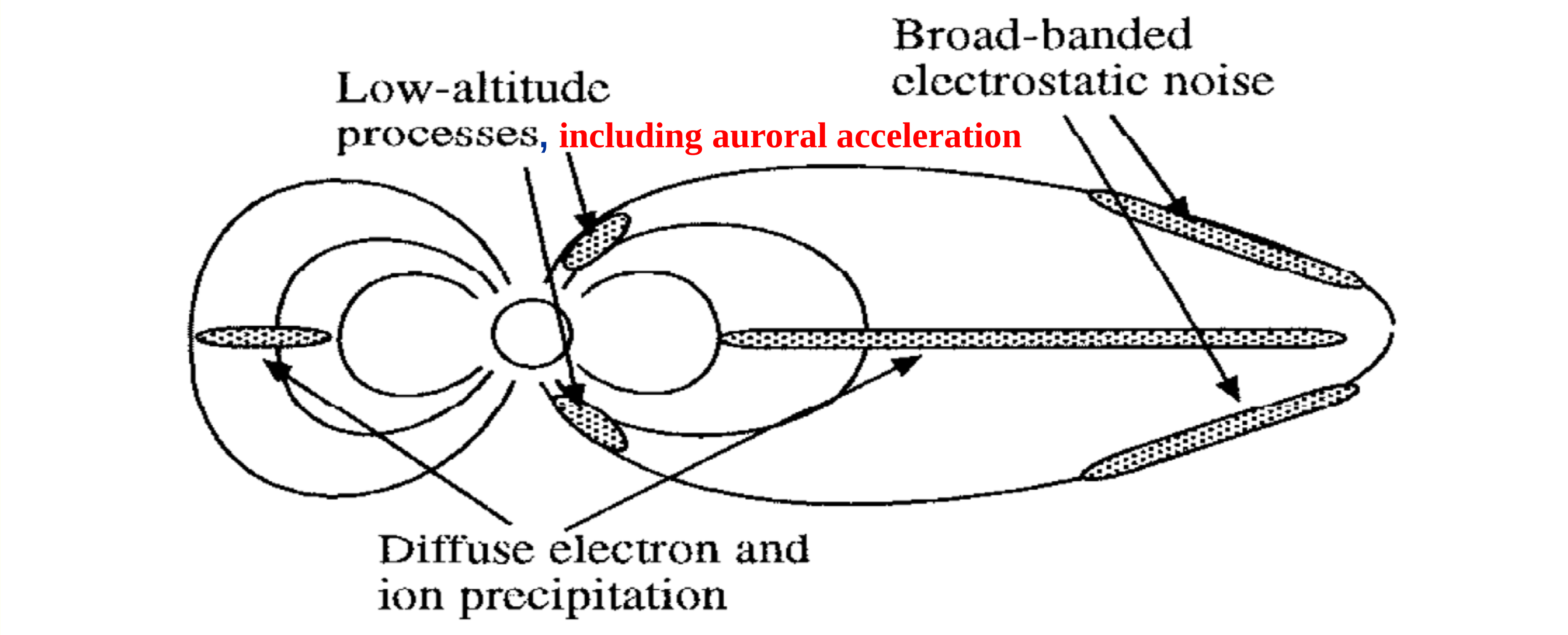
Satellite signatures of U potential





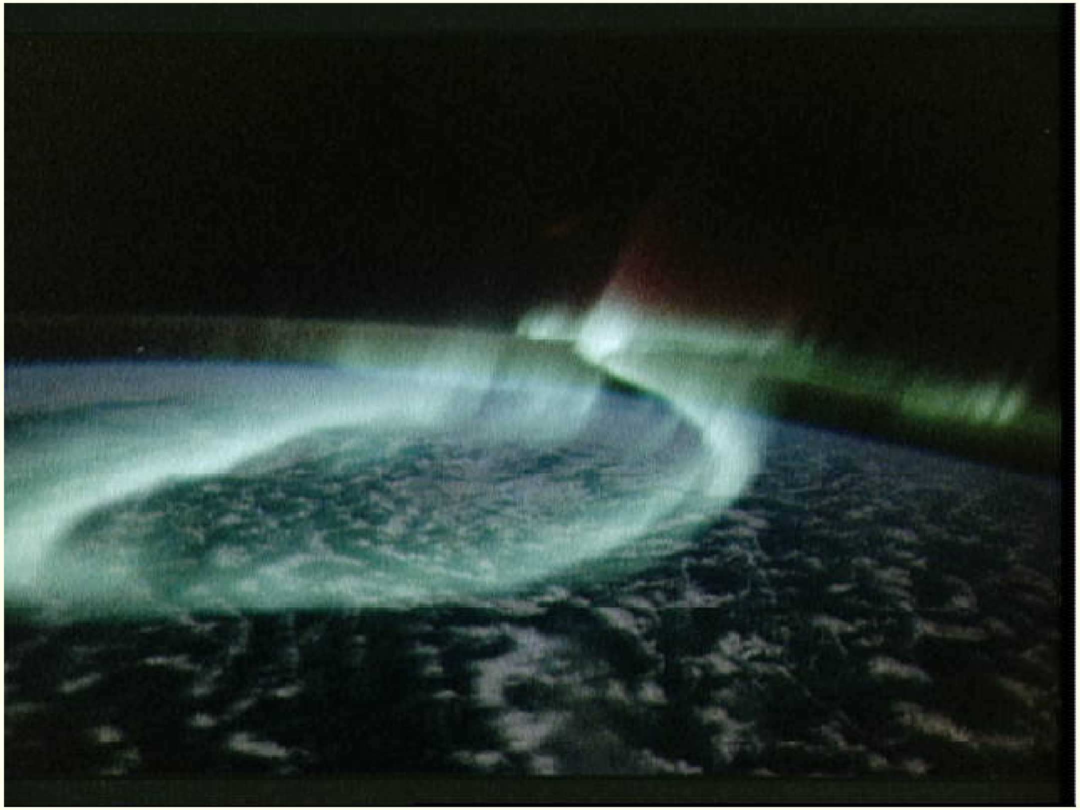
Measurements made by the ISEE satellite
(Mozer et al., 1977)

Acceleration regions



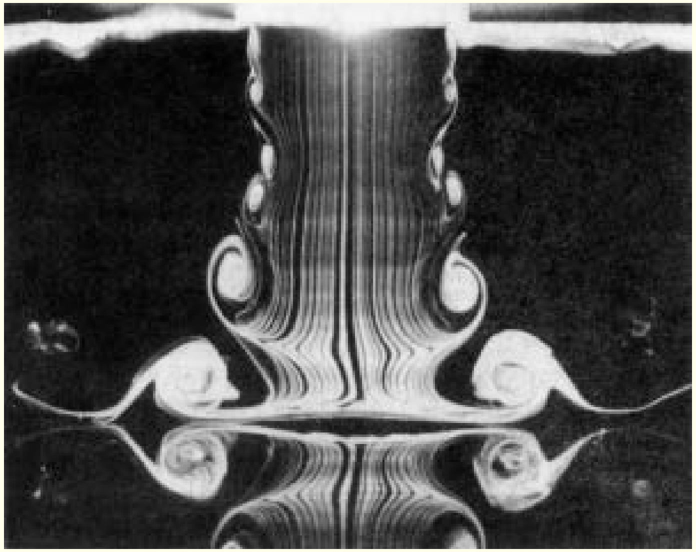
Auroral acceleration region typically situated at altitude of 1-3 R_E

Auroral spirals

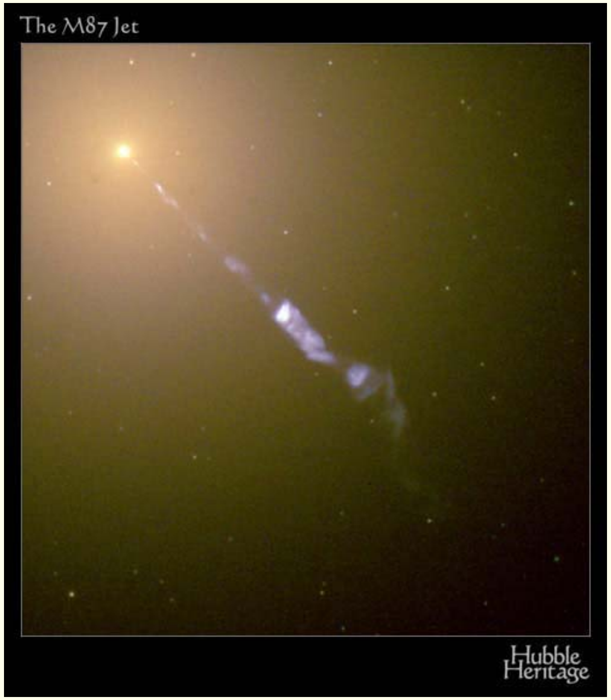


Develop when arcs become unstable

Kelvin-Helmholz-instability – a general phenomenon



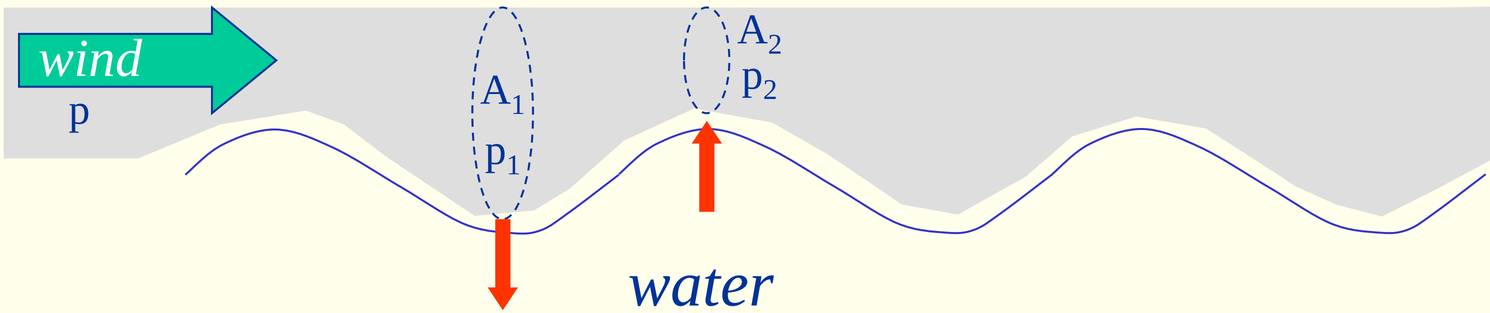
Aero- and fluid dynamics



Extragalactic jet (M87)

Cluds

Kelvin-Helmholz instability
Example: water waves



Continuity equation:

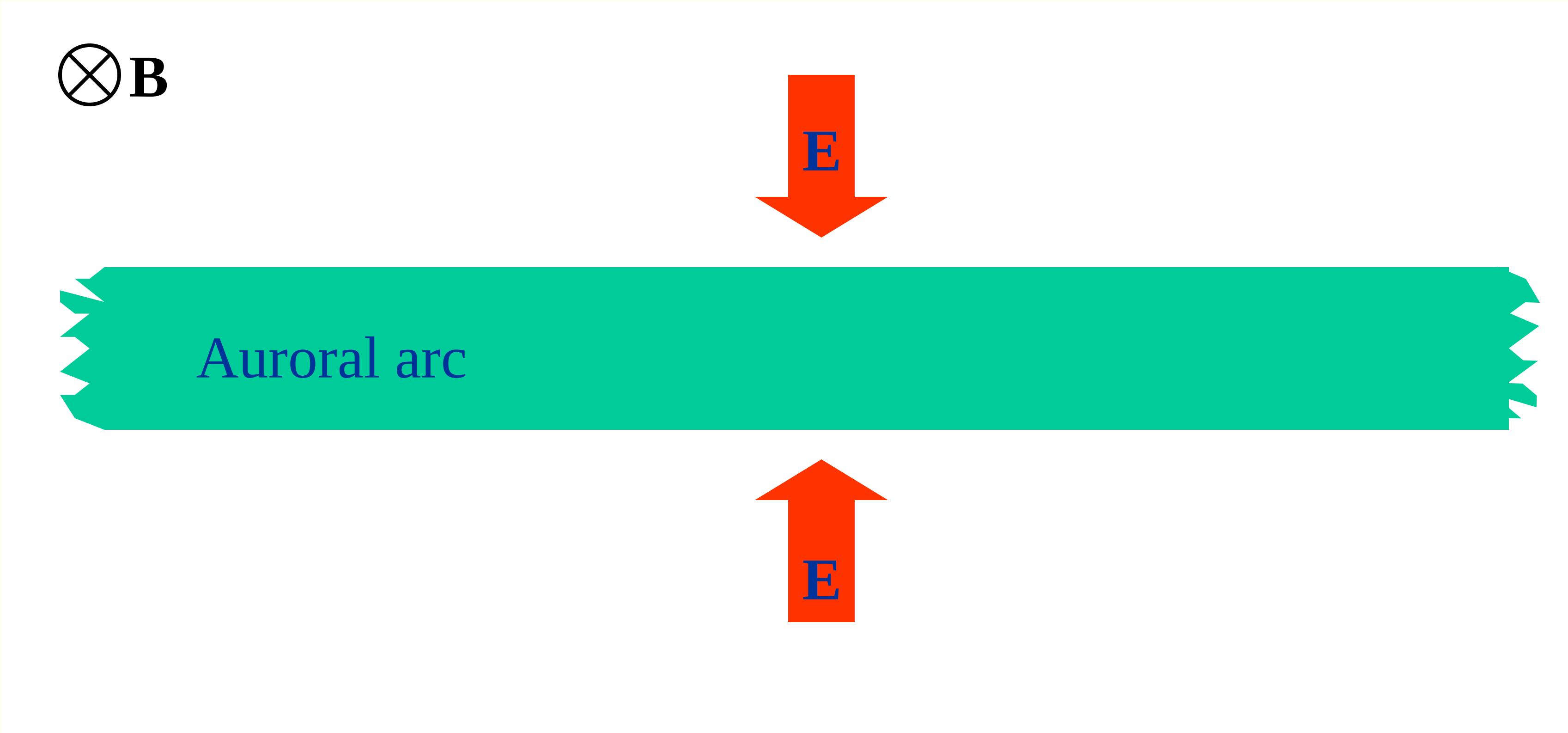
$$A_1 v_1 = A_2 v_2$$

Bernoulli's equation:

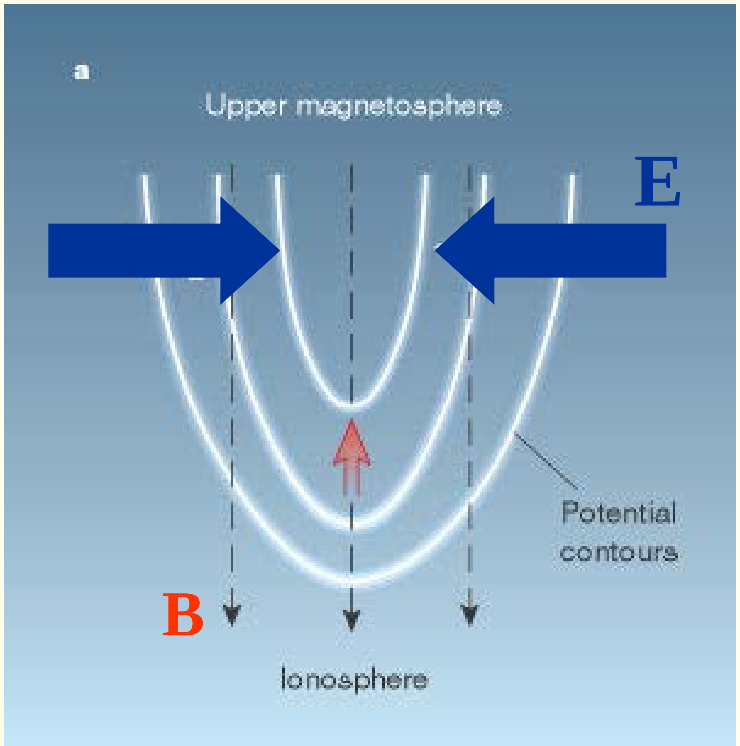
$$p_1 + \rho v_1^{\,2} = p_2 + \rho v_2^{\,2} = const.$$

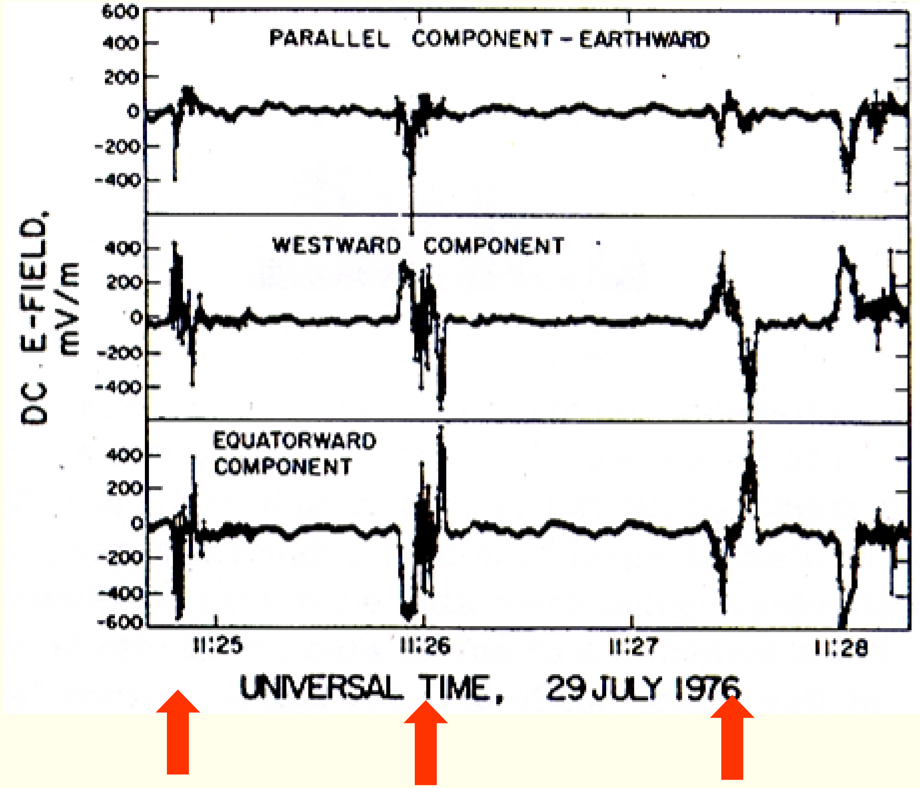
$$\because\ p_1 > p > p_2$$

Spirals – Kelvin-Helmholz instability



Satellite signatures of U potential





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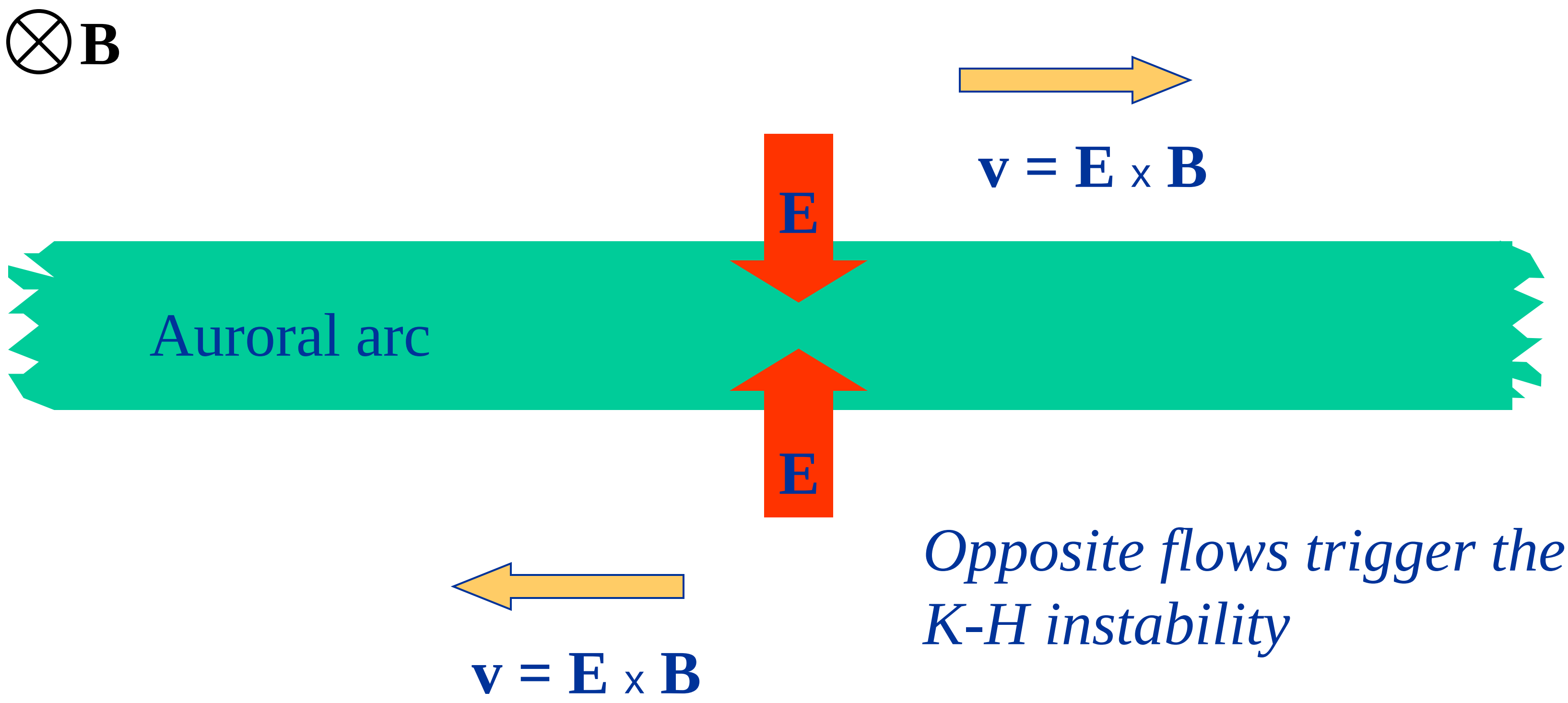
Spirals – Kelvin-Helmholz instability



Opposite flows trigger the K-H instability

At what planets do you expect aurora to exist?

Blue	Earth, Mercury, Jupiter, Saturn
Yellow	Earth, Venus, Jupiter, Saturn, Uranus, Neptune
Green	Earth, Mars, Jupiter, Saturn, Uranus, Neptune
Red	Earth, Jupiter, Saturn, Uranus, Neptune

What do we need to have an aurora?

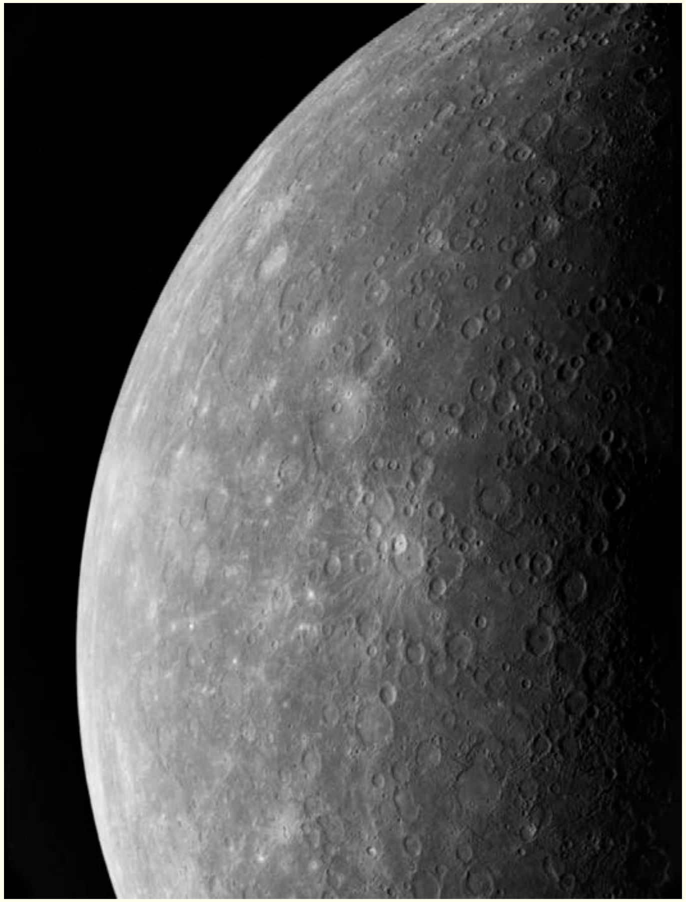
- Magnetic field (to guide the plasma particles towards the planet)
- Atmosphere (to create emissions)

At what planets do you expect aurora to exist?

Red

Earth, Jupiter, Saturn, Uranus, Neptune

Mercury



- No atmosphere
- X-ray aurora???
  Can possibly be created by electrons colliding directly with the planetary surface and lose their energy in one single collision.

Jupiter aurora

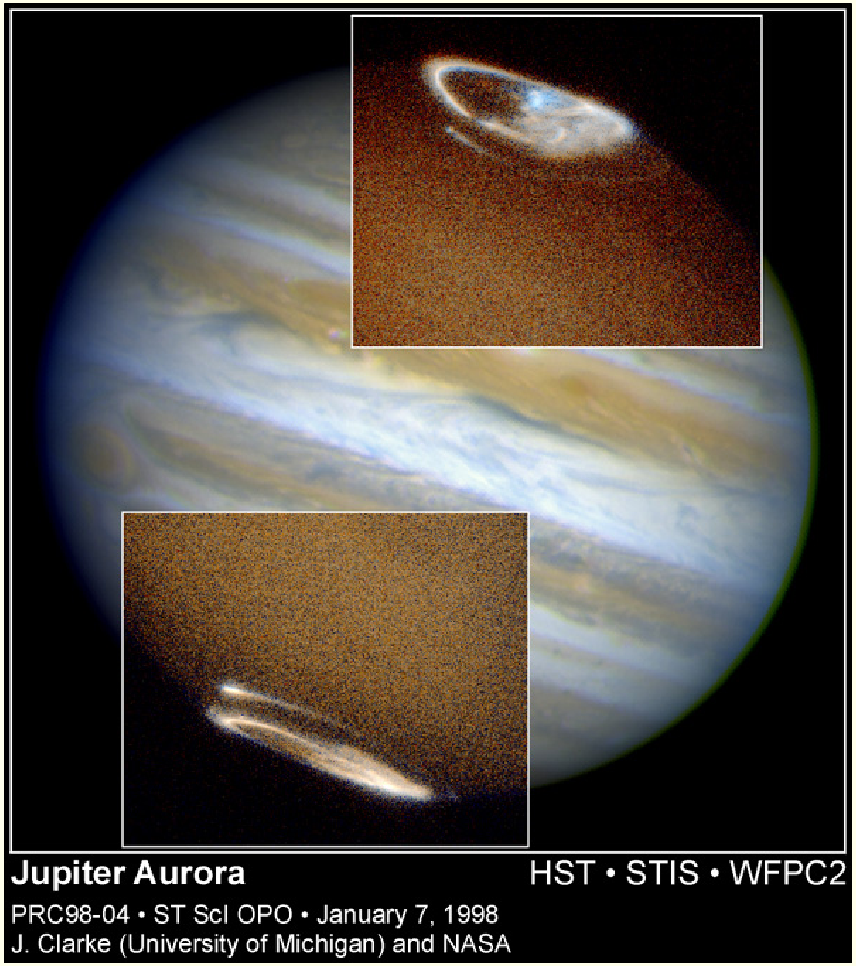
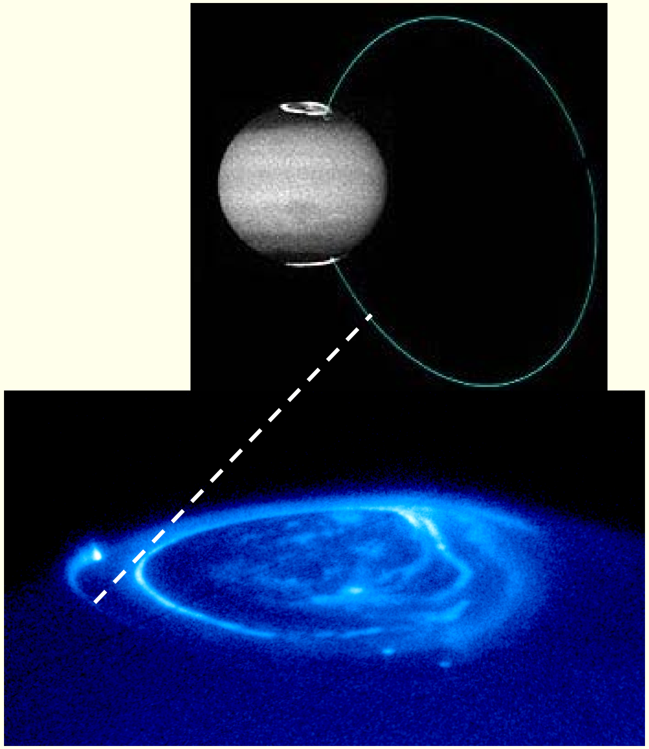


Foto från Hubble Space Telescope

- Jupiter's aurora has a power of ~1000 TW *(compare Earth: ~100 GW, nuclear power plant: ~1 GW)*
- Note the "extra" oval on Io's flux tube!



Jupiter and Io

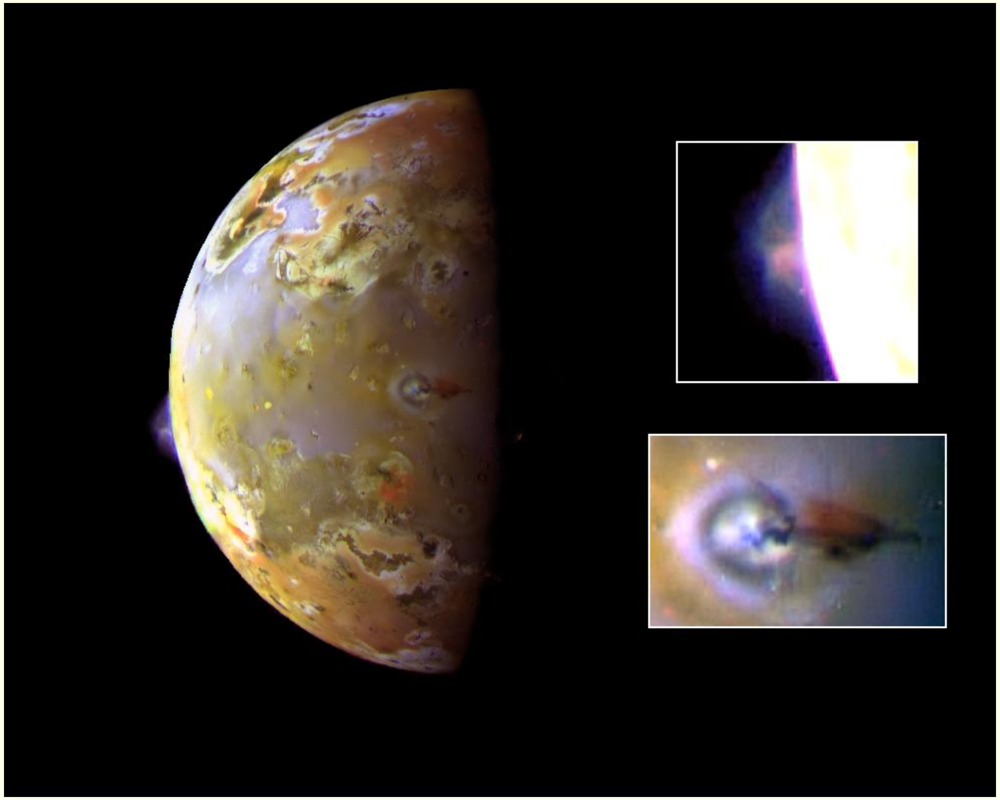
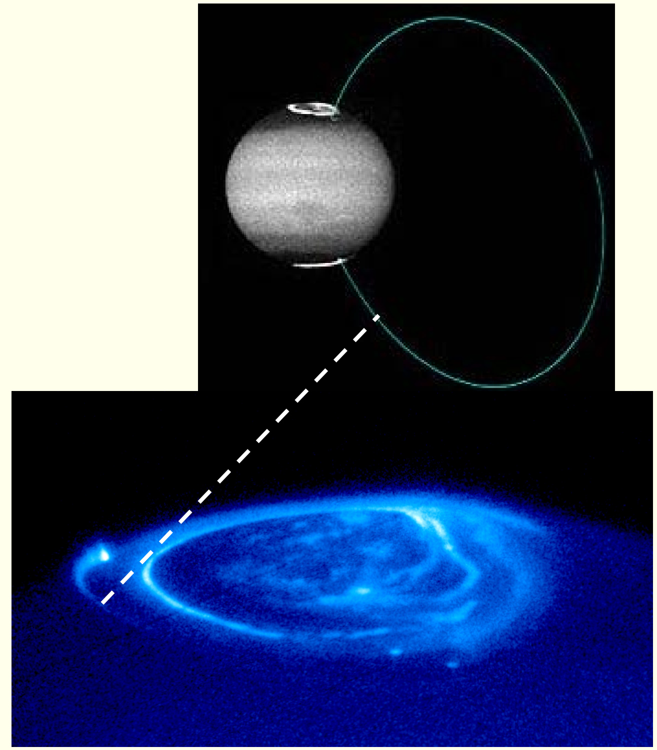


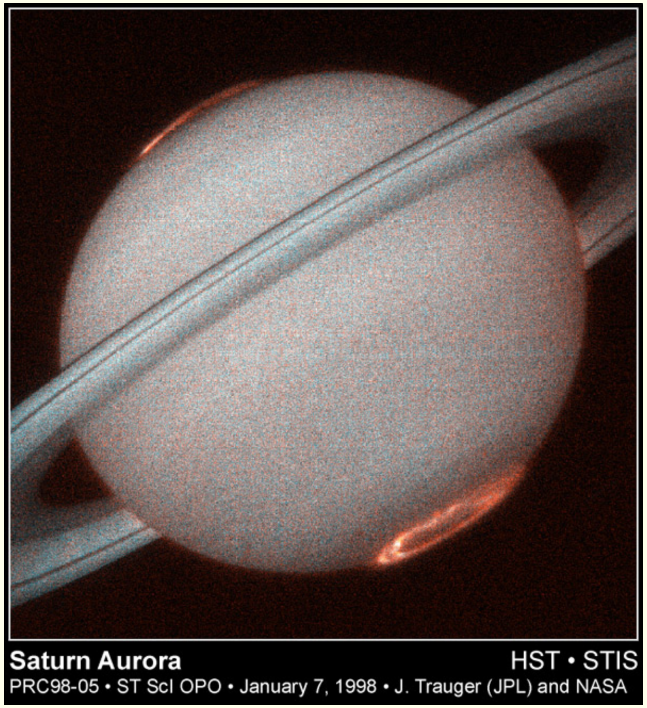
Photo from rymdsonden Galileo



The Jupiter moon Io is very volcanically active, and deposes large amounts of dust and gas in Jupiter’s magnetosphere. This is ionized by the sunlight, and the charged plasma partícles follow Jupiter’s magnetic field lines towards the atmosphere and cause auroral emissions.

Aurora of the other planets

Saturn



Saturnus' aurora: not noticeably different from Jupiter's, but much weaker. (Total power about the same as Earth's aurora.)

Uranus: *Auora detected in UV. Probably associated with Uranus' ring current/radiotion belts and not very dynamic.*

Neptunus: *weak UV aurora detected.*

Mars, Venus: *No aurora.*

Prerequisites for…

Life

- Energy source (sun)
- Atmosphere
- Magnetic field
- Water

Aurora

- Energy source (sun)
- Atmosphere
- Magnetic field

On space weather and viewing aurora

Some space weather sites

http://spaceweather.com/

http://www.esa-spaceweather.net/

http://sunearthday.nasa.gov/swac/

http://www.noaawatch.gov/themes/space.php

http://www.windows2universe.org/spaceweather/more_details.html

Kiruna

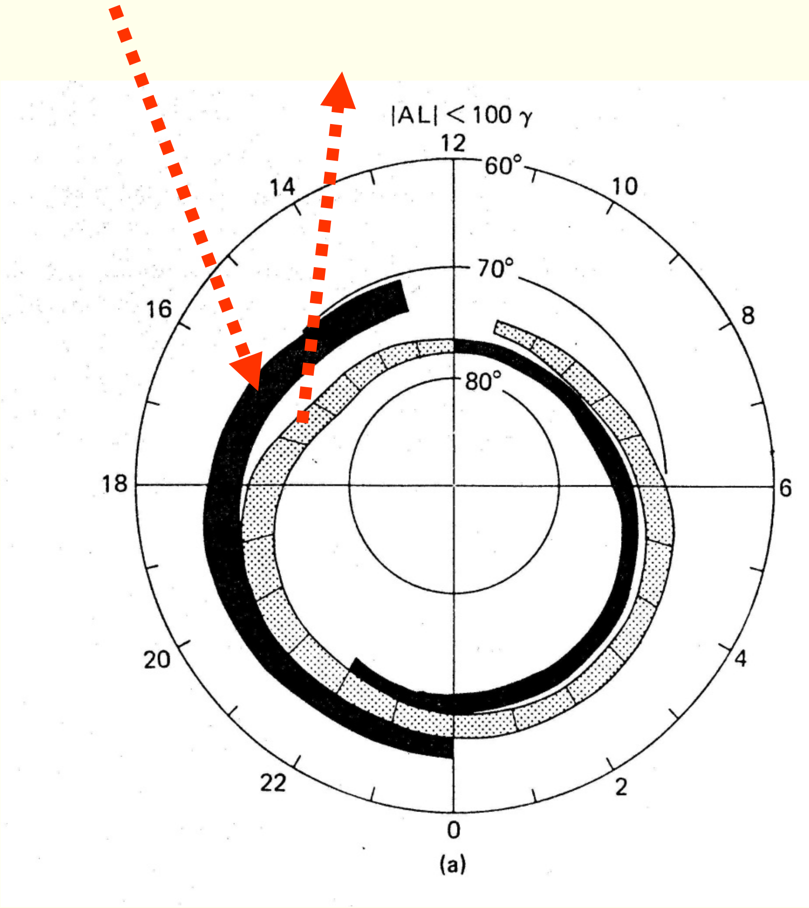
Kiruna all-sky camera:
http://www.irf.se/allsky/rtasc.php

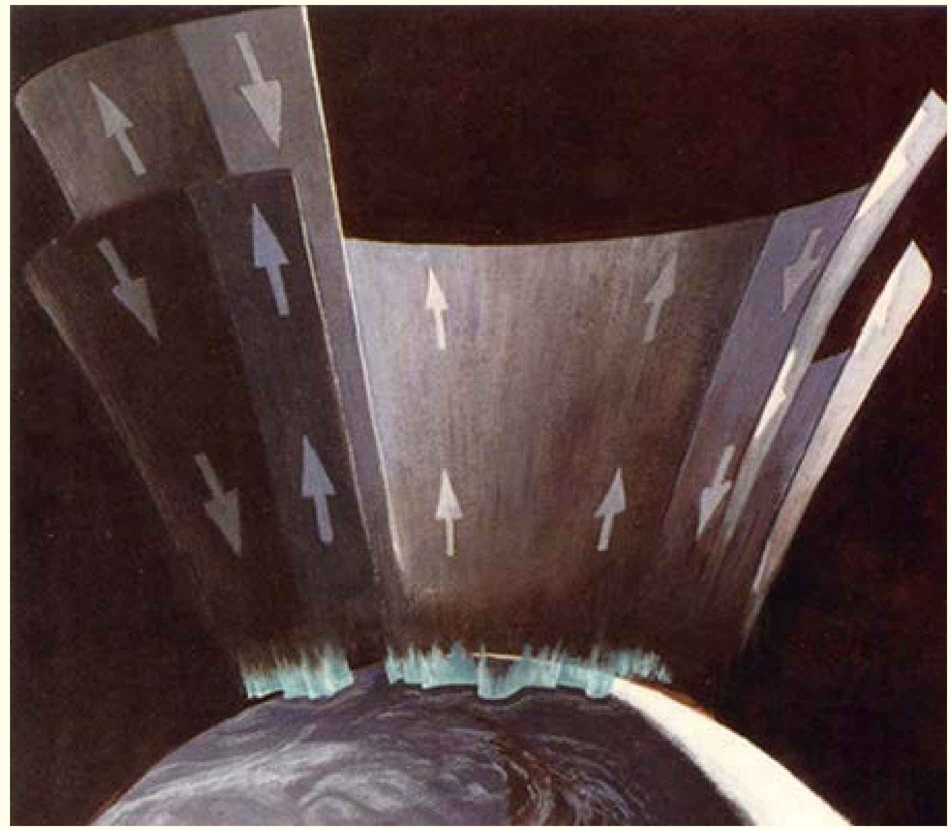
http://sunearthday.nasa.gov/swac/tutorials/aur_kiruna.php

Forecasts:
http://flare.lund.irf.se/rwc/aurora/

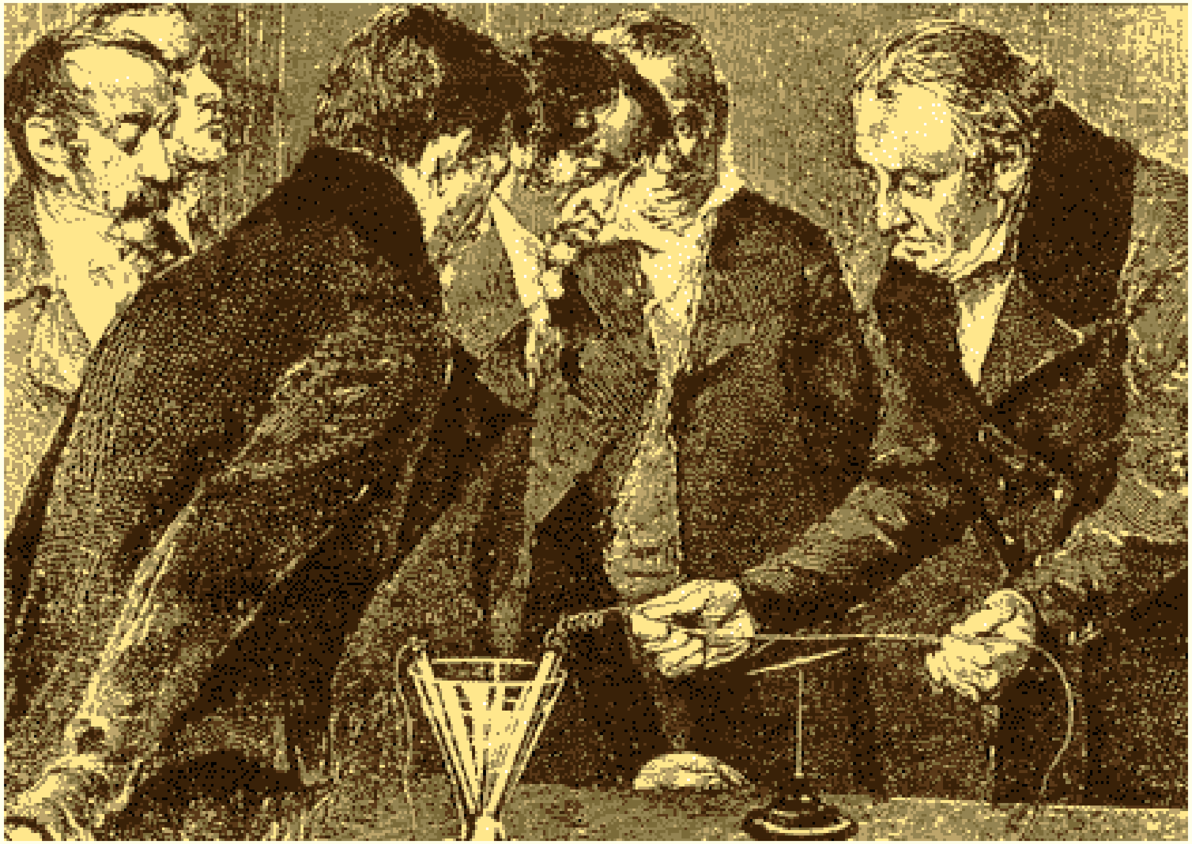
http://www.irf.se/Observatory/?link[All-skycamera]=Aurora_sp_statistics

Birkeland currents in the auroral oval

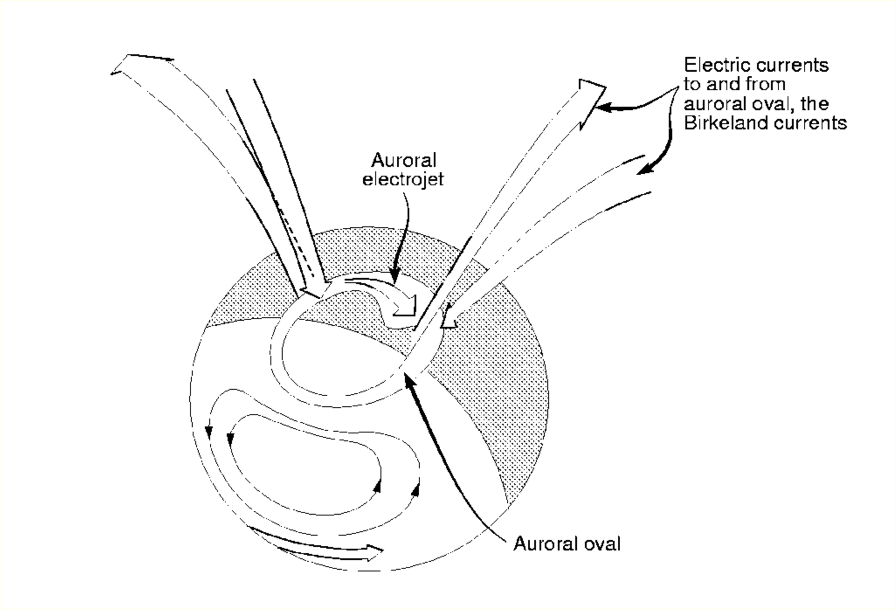




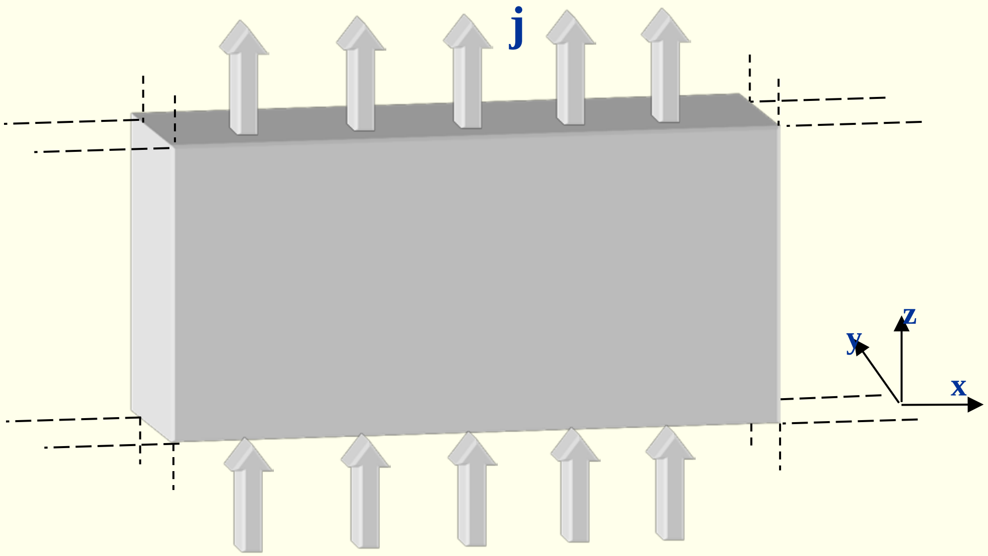
How can you measure currents in space?



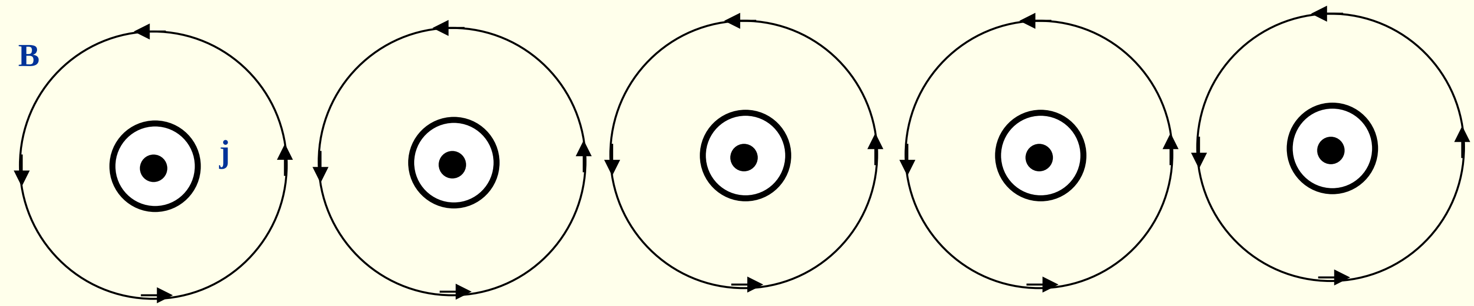
Current sheet approximation



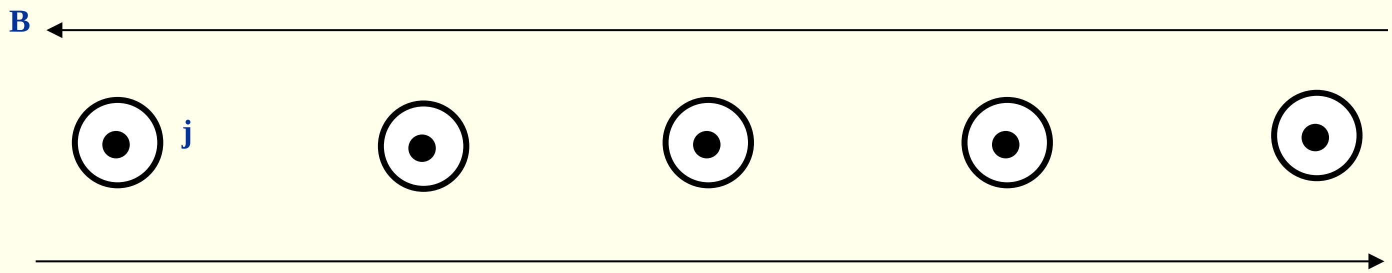
Approximate currents by thin current sheets with infinite size in the x- och z-directions.



Current sheet approximation

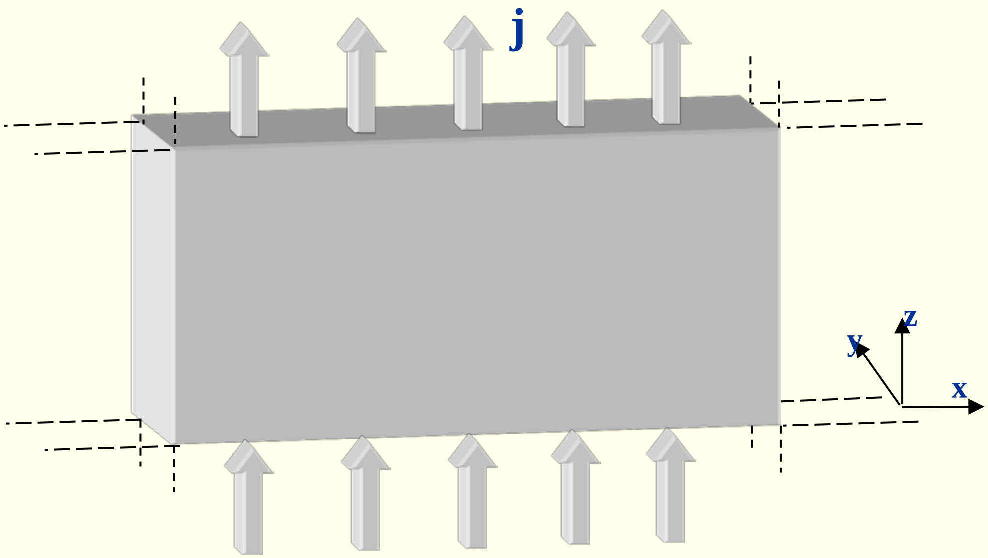


What will the magnetic field around such a current configuration be? Start by approximating with line currents to get a qualitative picture.



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

Current sheet approximation and Ampére's law



$$\left(\frac{\partial B_z}{\partial y}-\frac{\partial B_y}{\partial z},\ \frac{\partial B_x}{\partial z}-\frac{\partial B_z}{\partial x},\ \frac{\partial B_y}{\partial x}-\frac{\partial B_x}{\partial y}\right)=\mu_0\left(j_x,\ j_y,\ j_z\right)$$

But $\frac{\partial}{\partial x}=0$ and $\frac{\partial}{\partial z}=0$

$$\left(\frac{\partial B_z}{\partial y},\ 0,\ -\frac{\partial B_x}{\partial y}\right)=\mu_0\left(0,\ 0,\ j_z\right)$$

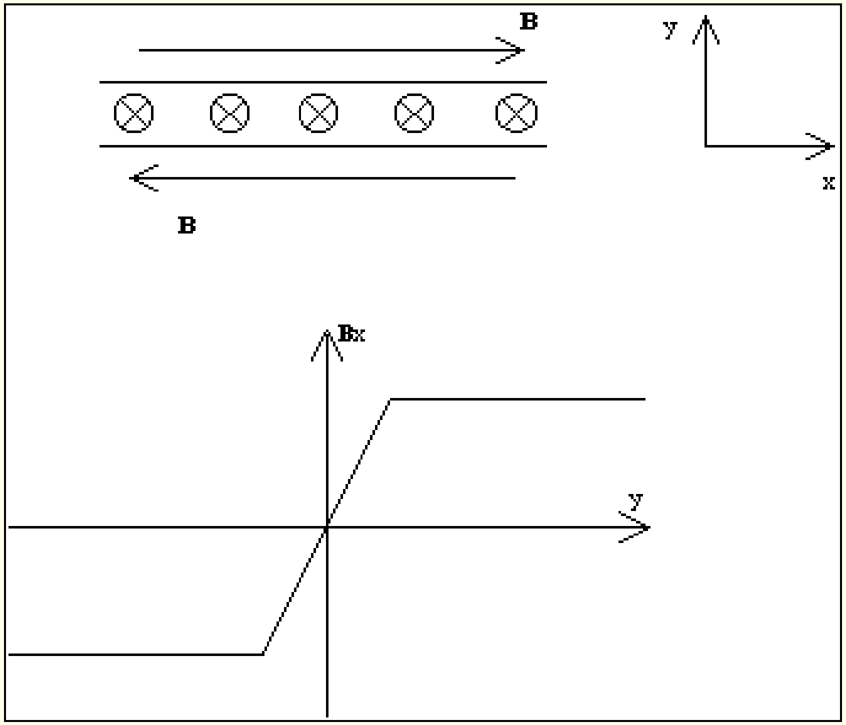
eller

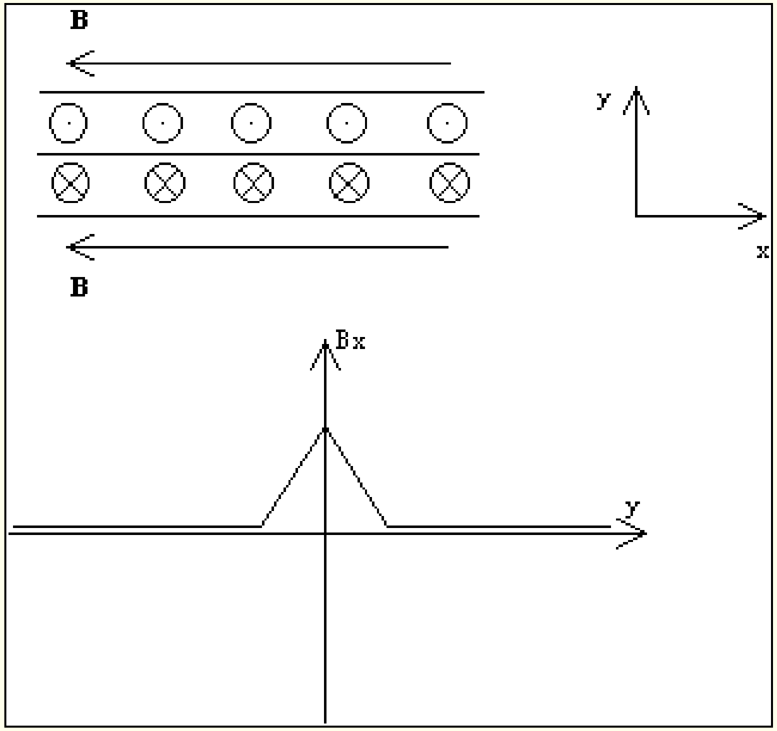
Ampére's law (no time dependence):

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

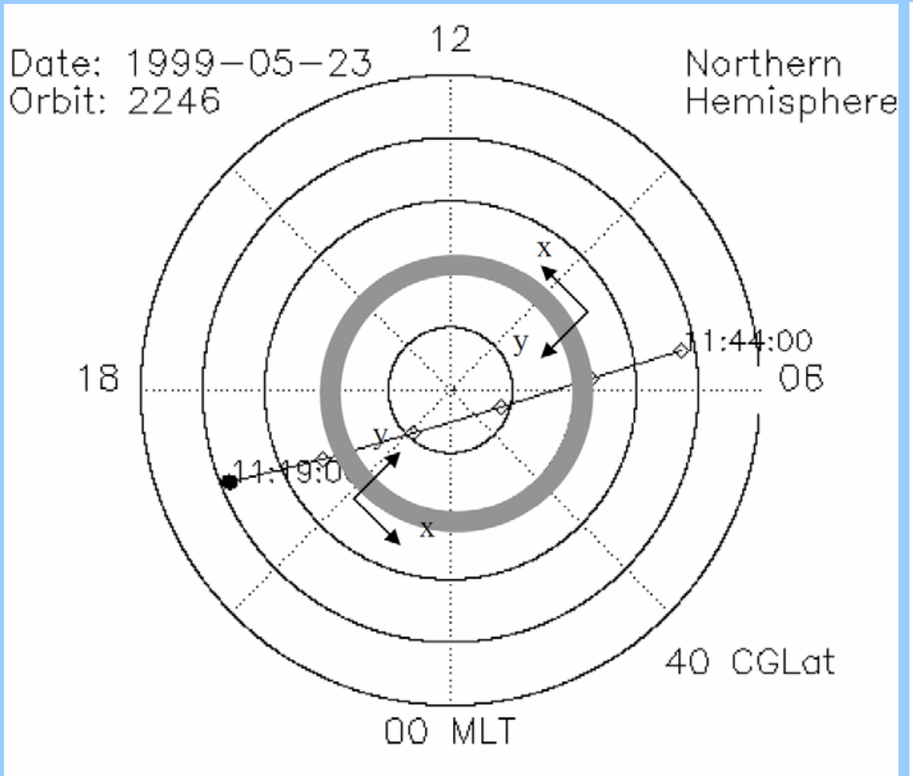
$$j_z=-\frac{1}{\mu_0}\frac{\partial B_x}{\partial y}$$

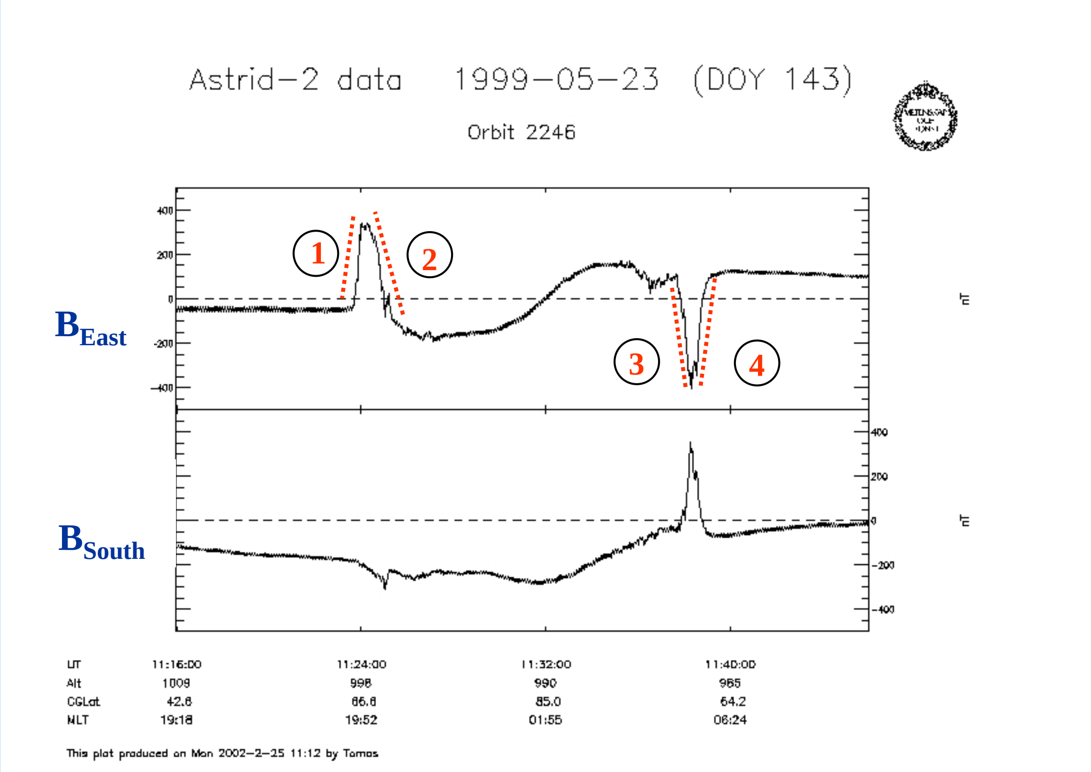
Current sheet - example





$$j_z = -\frac{1}{\mu_0}\frac{\partial B_x}{\partial y}$$



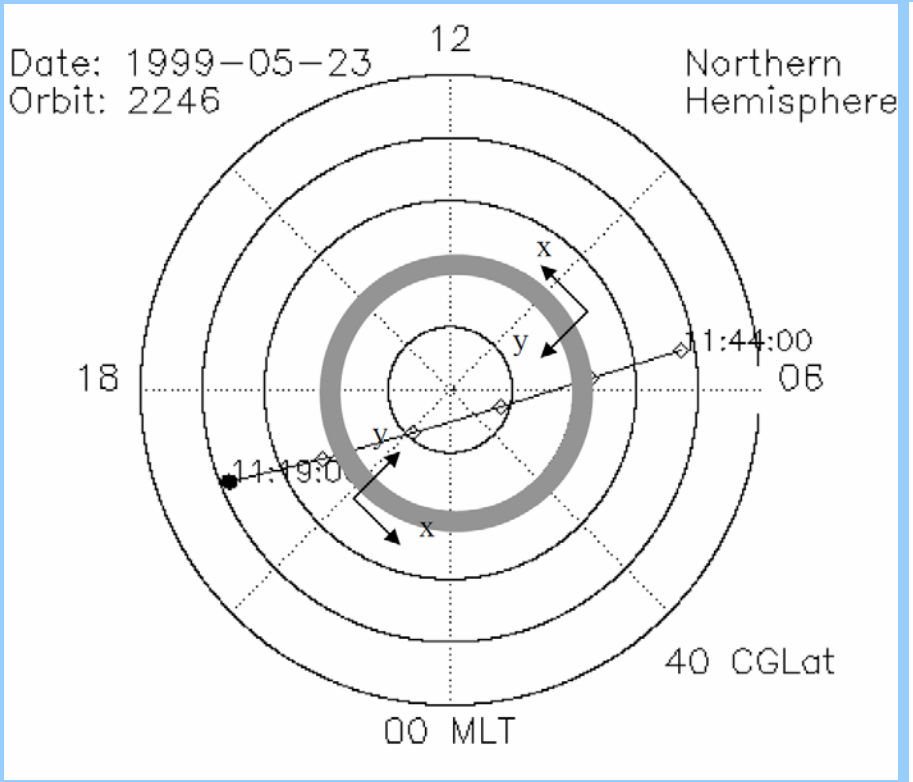


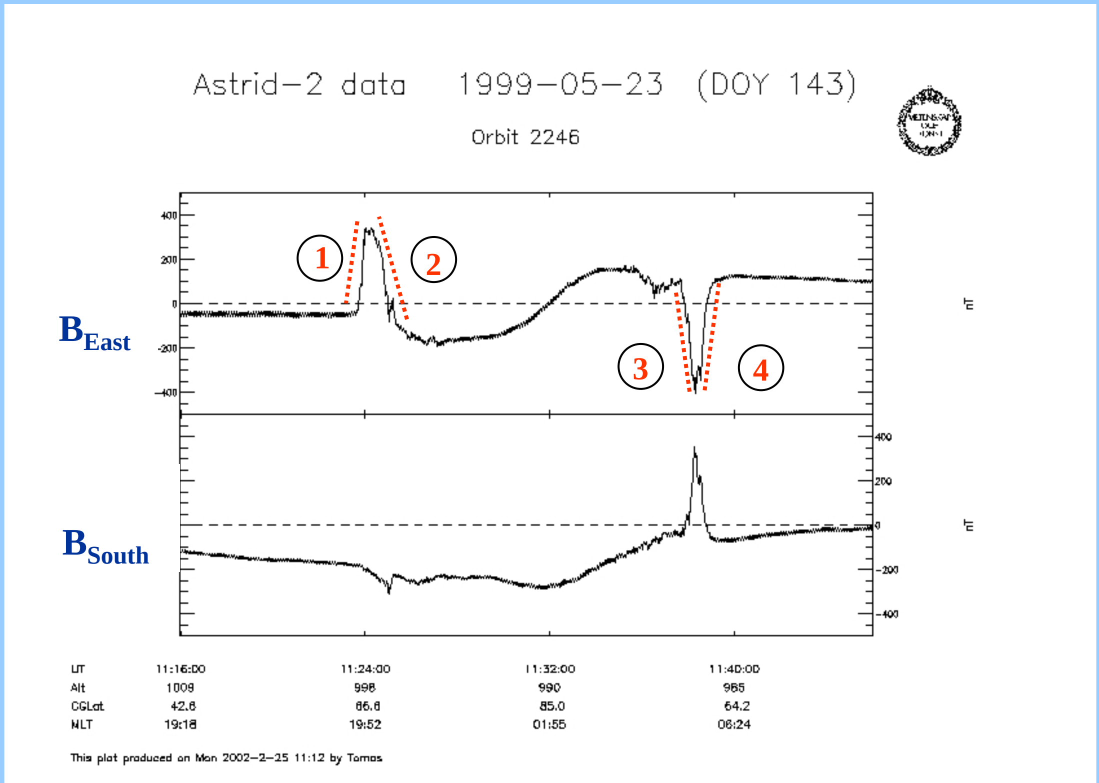
$$j_z = -\frac{1}{\mu_0}\frac{\partial B_x}{\partial y}$$

What is the direction of the current in current sheet 1?

Blue — Into the ionosphere

Red — Out of the ionosphere





What is the direction of the current in current sheet 1?

$$j_z = -\frac{1}{\mu_0}\frac{\partial B_x}{\partial y}$$

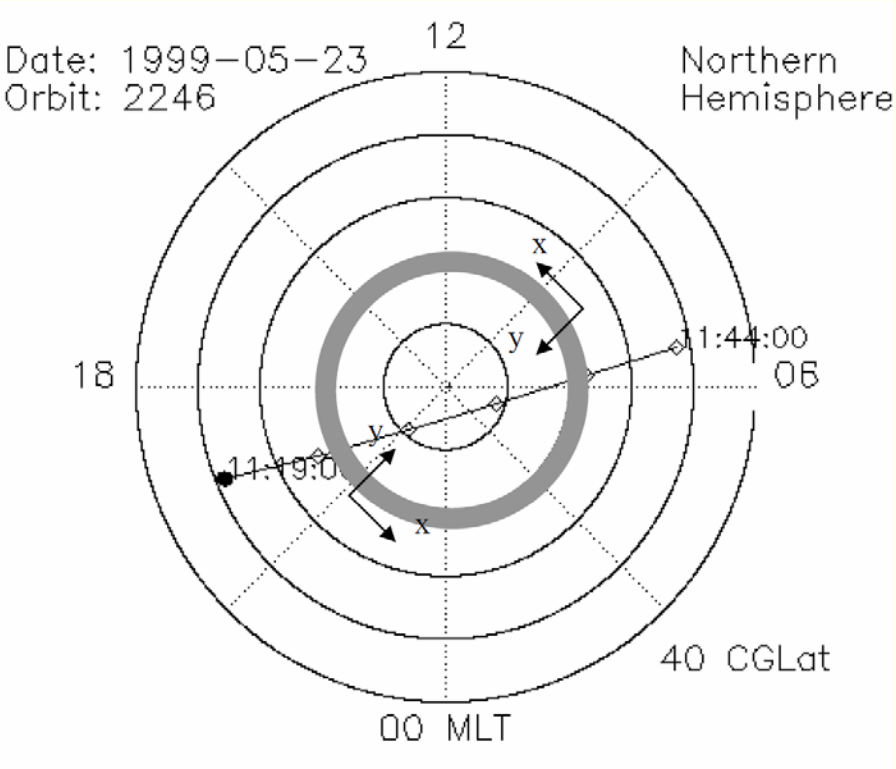
$$\frac{\partial B_x}{\partial y} = \frac{\partial B_{East}}{\partial y} > 0$$

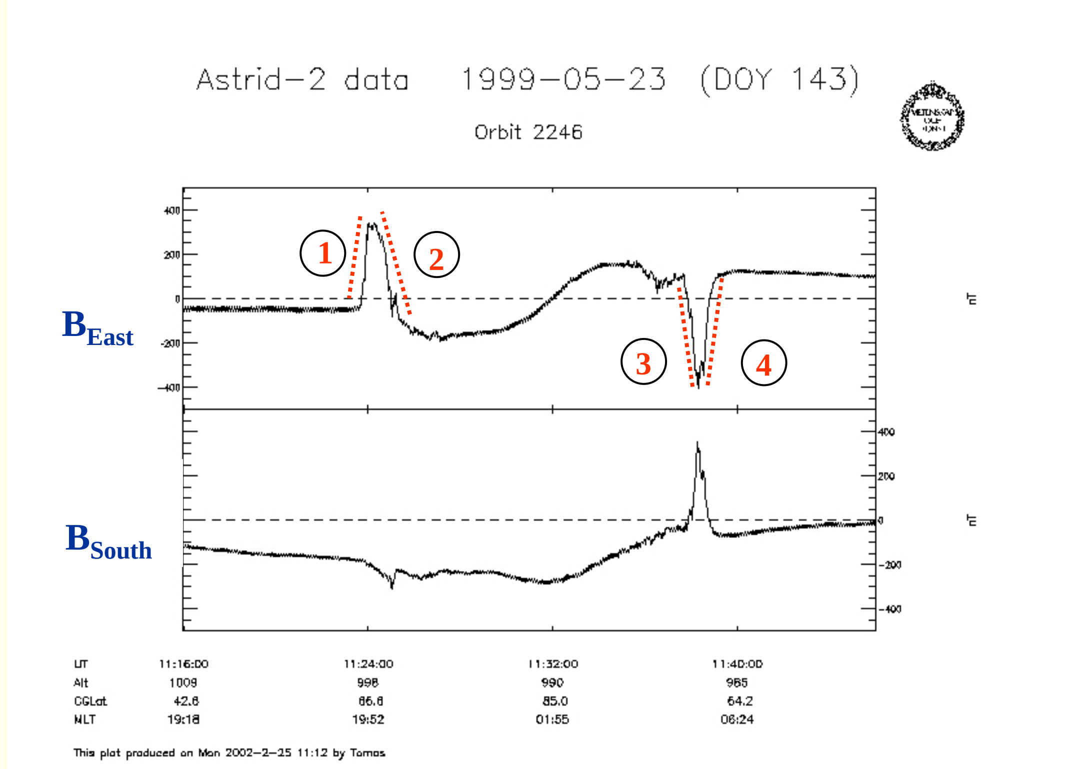
$$\Rightarrow$$

$$j_z < 0$$

Blue

Into the ionosphere

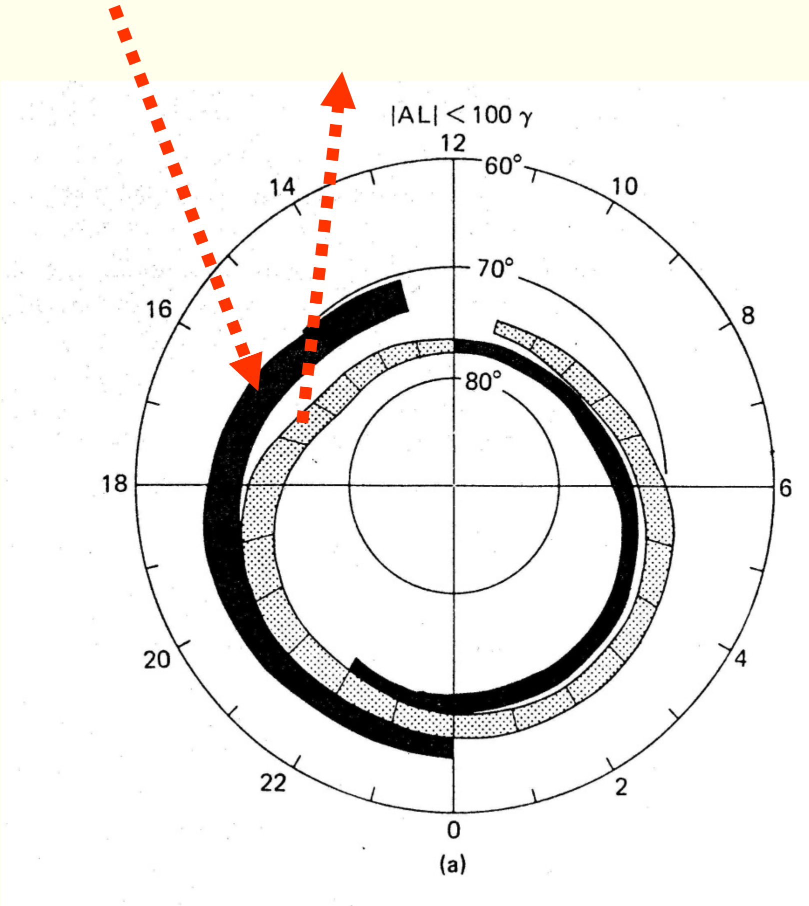


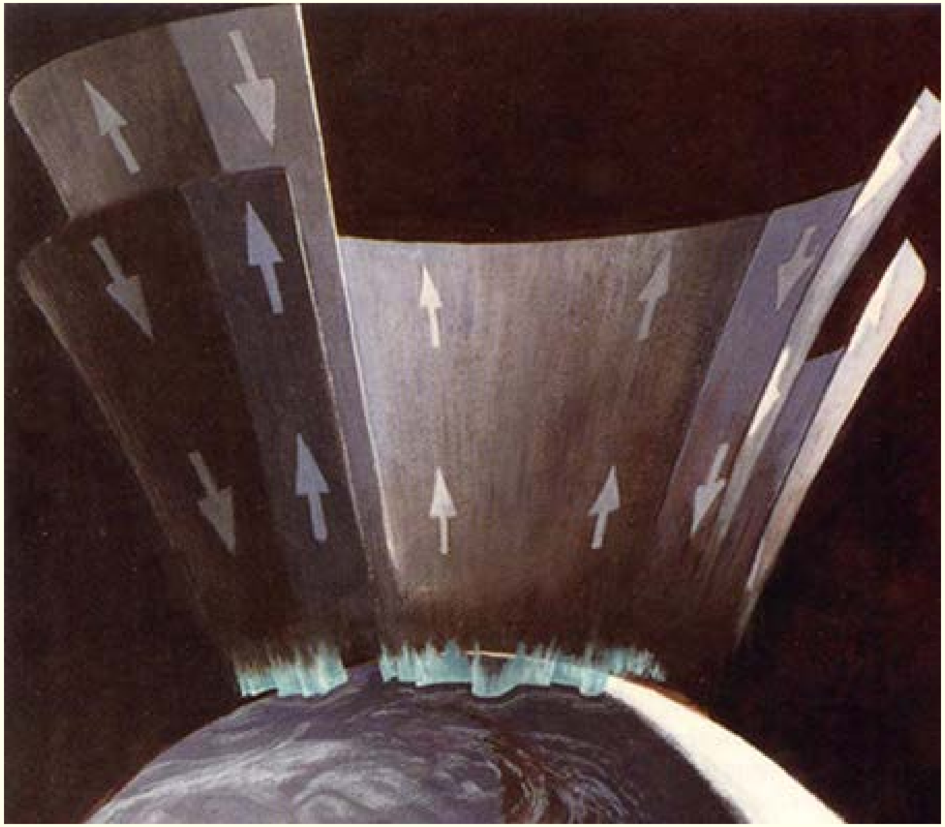


$$j_z = -\frac{1}{\mu_0}\frac{\partial B_x}{\partial y}$$

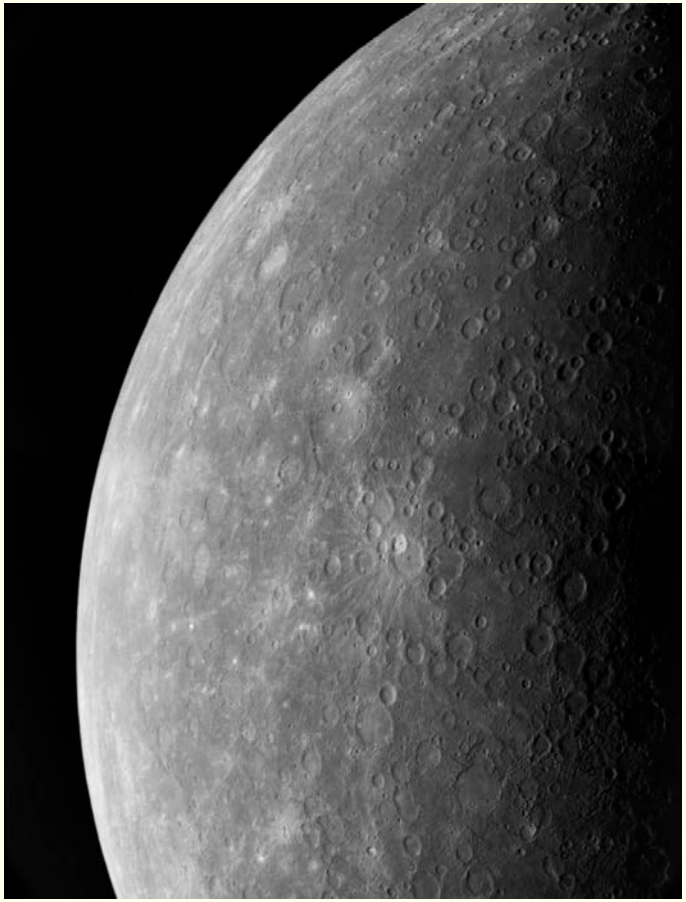
1)	$\frac{\partial B_x}{\partial y} > 0$	$\Rightarrow$	$j_z < 0$	Into the ionosphere
2)	$\frac{\partial B_x}{\partial y} < 0$	$\Rightarrow$	$j_z > 0$	Out of the ionosphere
3)	$\frac{\partial B_x}{\partial y} > 0$	$\Rightarrow$	$j_z < 0$	Into the ionosphere
4)	$\frac{\partial B_x}{\partial y} < 0$	$\Rightarrow$	$j_z > 0$	Out of the ionosphere

Birkeland currents in the auroral oval





Mercury



- No atmosphere
- X-ray aurora???
  Can possibly be created by electrons colliding directly with the planetary surface and lose their energy in one single collision.

Jupiter aurora

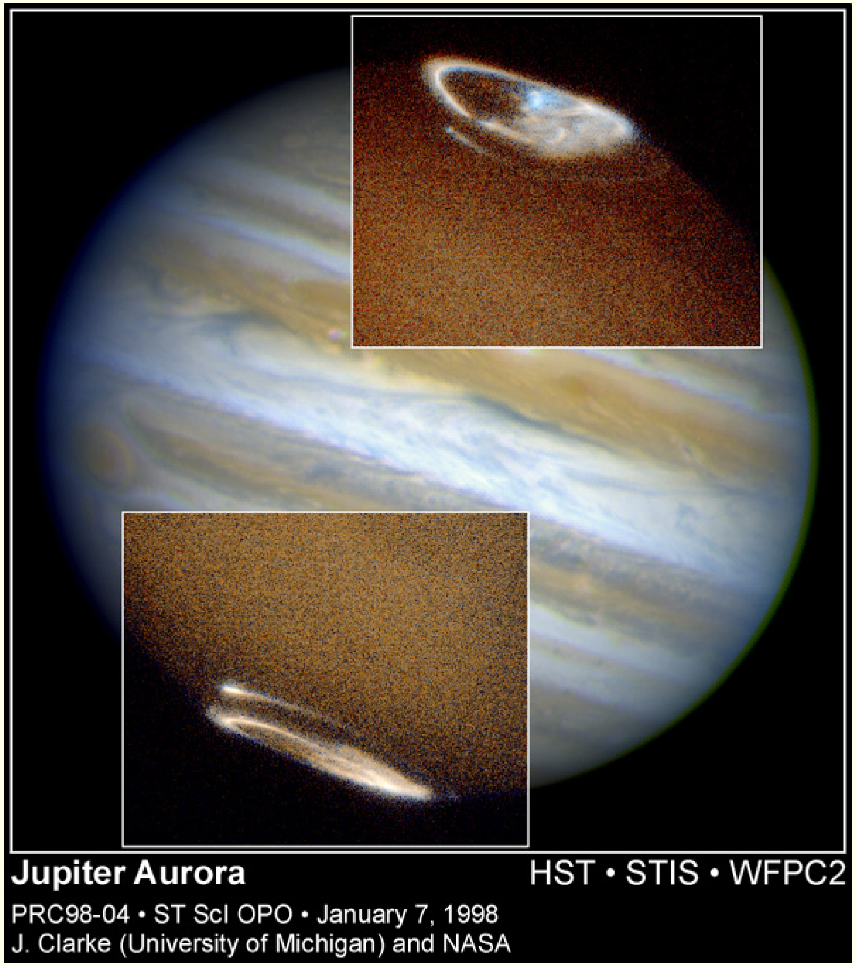
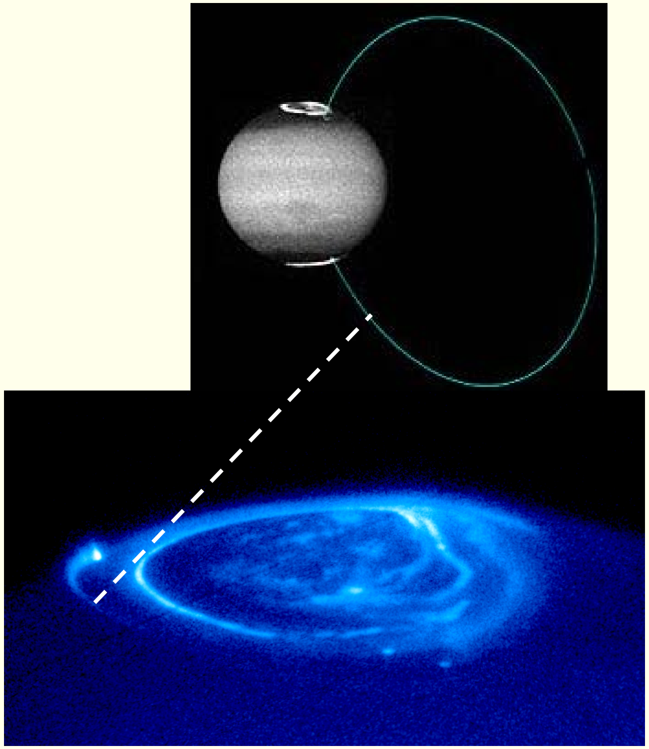


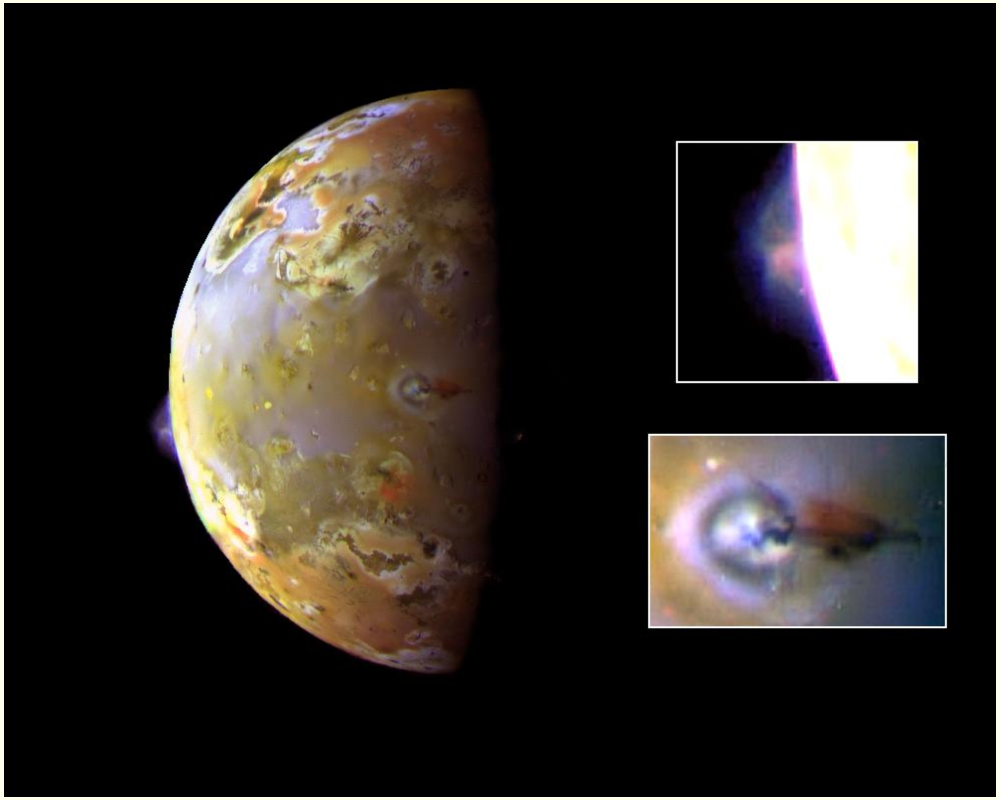
Foto från Hubble Space Telescope

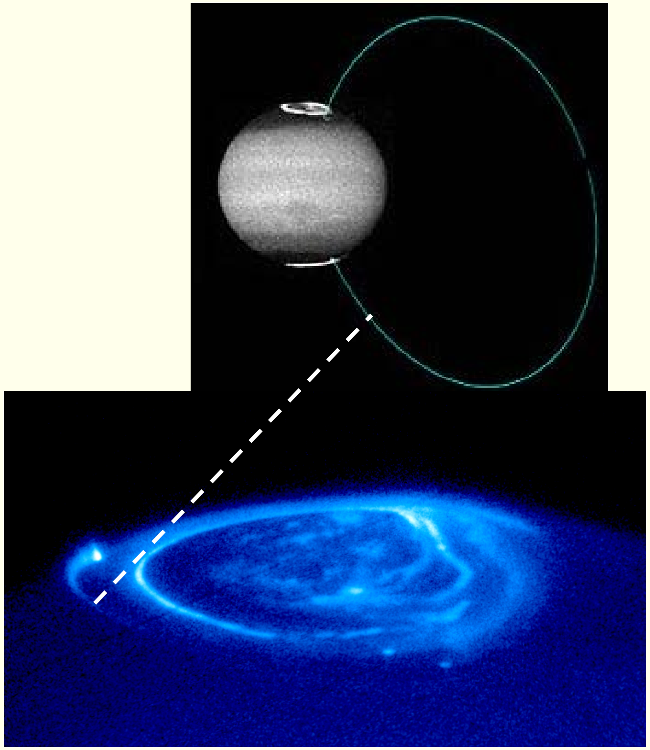
- Jupiter’s aurora has a power of ~1000 TW *(compare Earth: ~100 GW, nuclear power plant: ~1 GW)*
- Note the “extra” oval on Io’s flux tube!



Jupiter and Io

Photo from rymdsonden Galileo

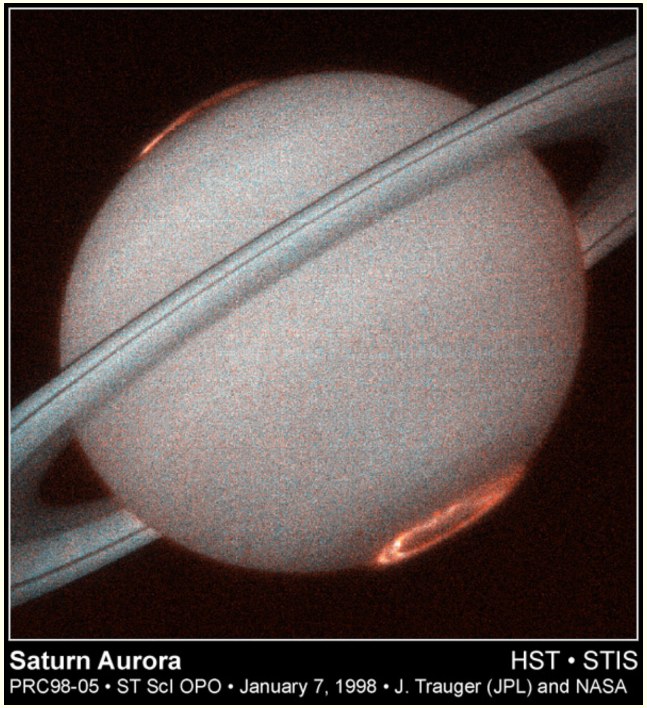




The Jupiter moon Io is very volcanically active, and deposes large amounts of dust and gas in Jupiter's magnetosphere. This is ionized by the sunlight, and the charged plasma partícles follow Jupiter's magnetic field lines towards the atmosphere and cause auroral emissions.

Aurora of the other planets

Saturn



Saturnus' aurora: not noticeably different from Jupiter's, but much weaker. (Total power about the same as Earth's aurora.)

Uranus: *Auora detected in UV. Probably associated with Uranus' ring current/radiotion belts and not very dynamic.*

Neptunus: *weak UV aurora detected.*

Mars, Venus: *No aurora.*

Prerequisites for…

Life

- Energy source (sun)
- Atmosphere
- Magnetic field
- Water

Aurora

- Energy source (sun)
- Atmosphere
- Magnetic field

At what planets do you expect aurora to exist?

Blue	Earth, Mercury, Jupiter, Saturn
Yellow	Earth, Venus, Jupiter, Saturn, Uranus, Neptune
Green	Earth, Mars, Jupiter, Saturn, Uranus, Neptune
Red	Earth, Jupiter, Saturn, Uranus, Neptune

What do we need to have an aurora?

- Magnetic field (to guide the plasma particles towards the planet)
- Atmosphere (to create emissions)

At what planets do you expect aurora to exist?

Red

Earth, Jupiter, Saturn, Uranus, Neptune

On space weather and viewing aurora

Some space weather sites

http://spaceweather.com/

http://www.esa-spaceweather.net/

http://sunearthday.nasa.gov/swac/

http://www.noaawatch.gov/themes/space.php

http://www.windows2universe.org/spaceweather/more_details.html

Kiruna

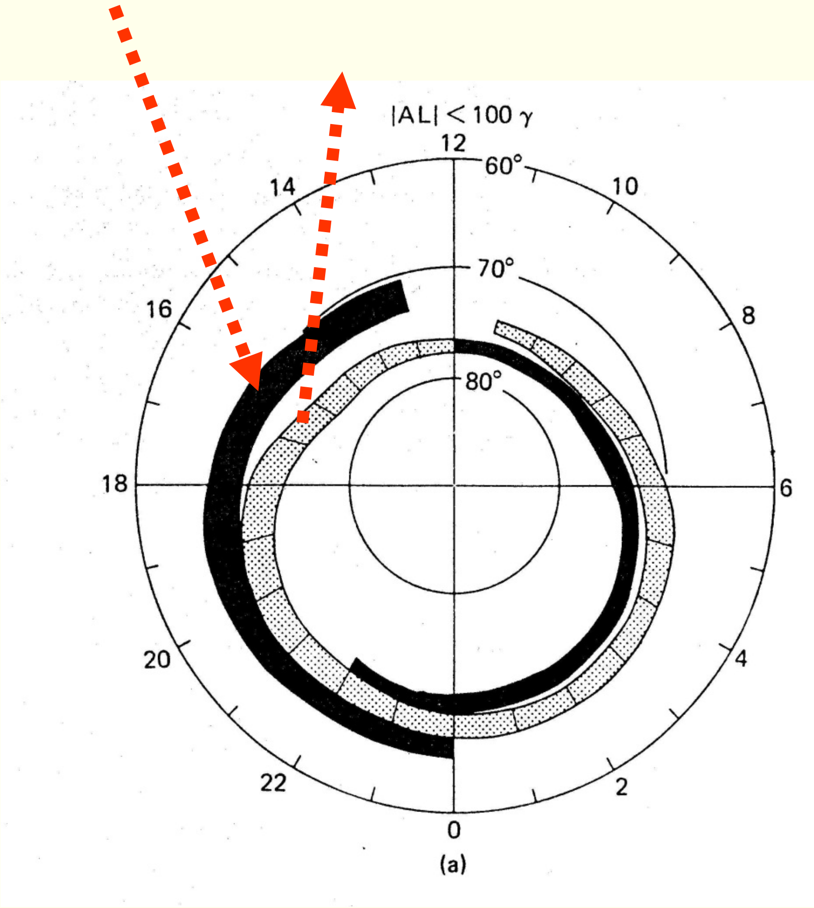
Kiruna all-sky camera:
http://www.irf.se/allsky/rtasc.php

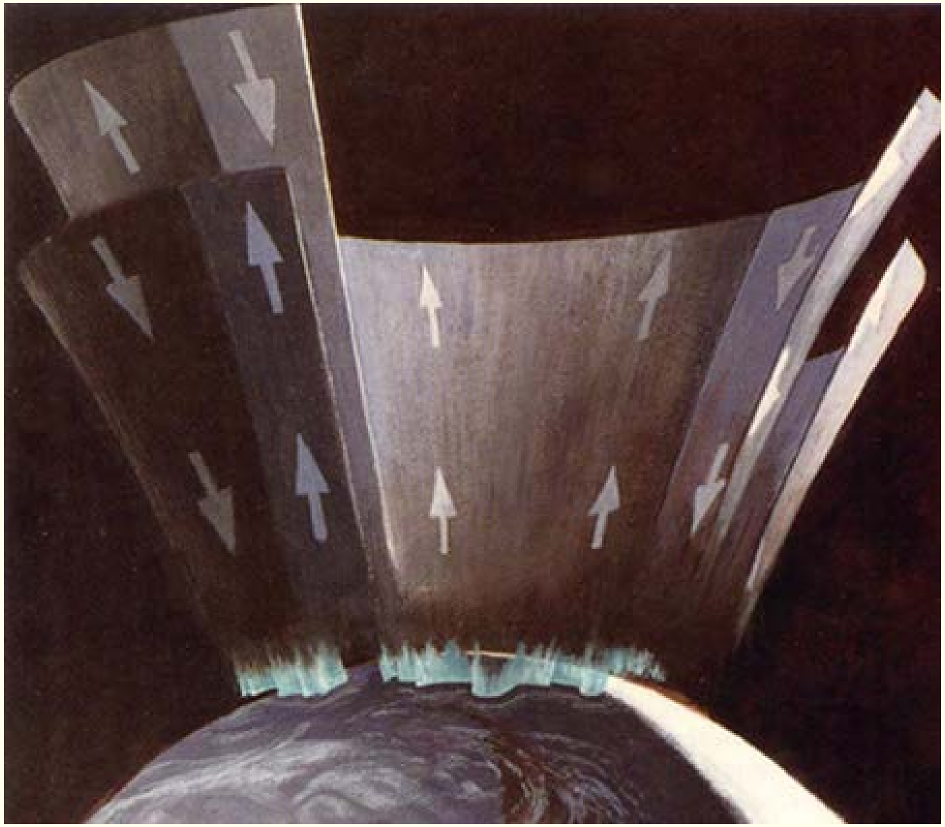
http://sunearthday.nasa.gov/swac/tutorials/aur_kiruna.php

Forecasts:
http://flare.lund.irf.se/rwc/aurora/

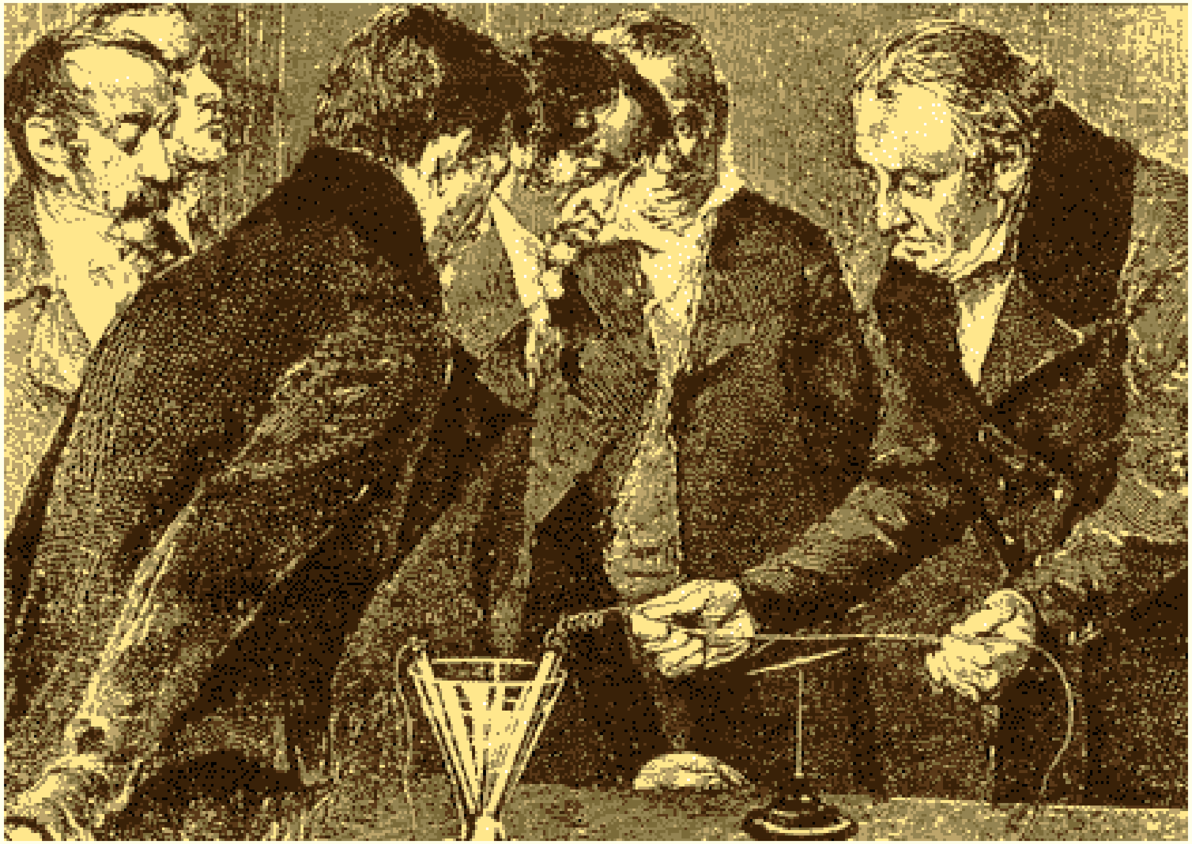
http://www.irf.se/Observatory/?link[All-skycamera]=Aurora_sp_statistics

Birkeland currents in the auroral oval

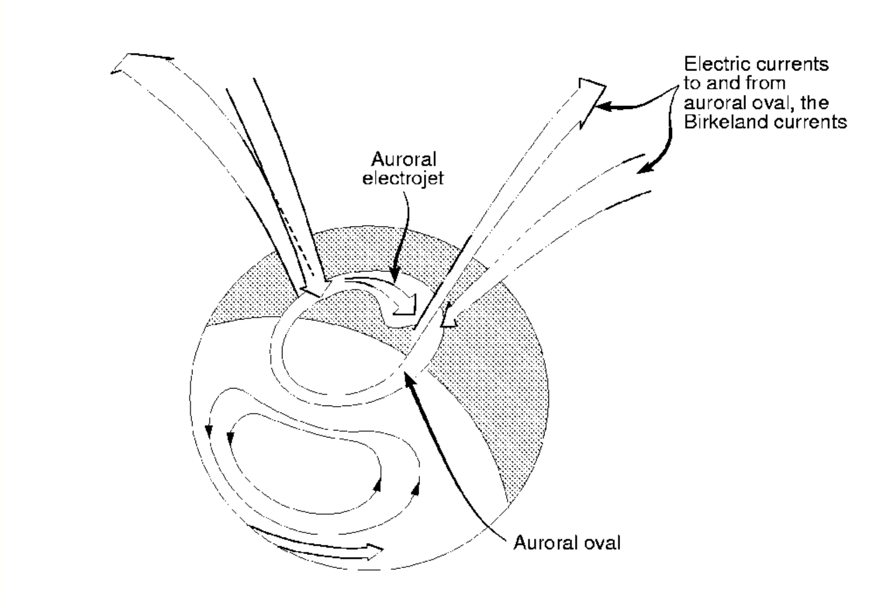




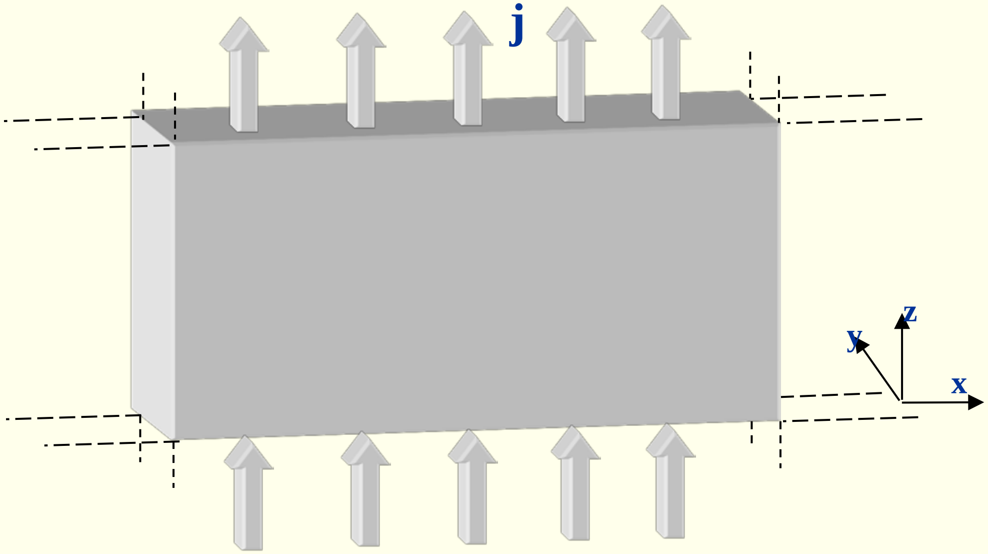
How can you measure currents in space?



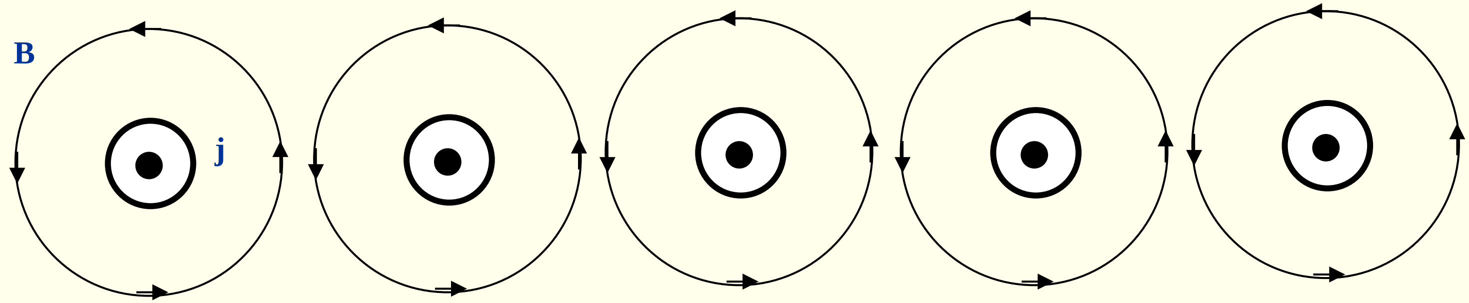
Current sheet approximation



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



Current sheet approximation



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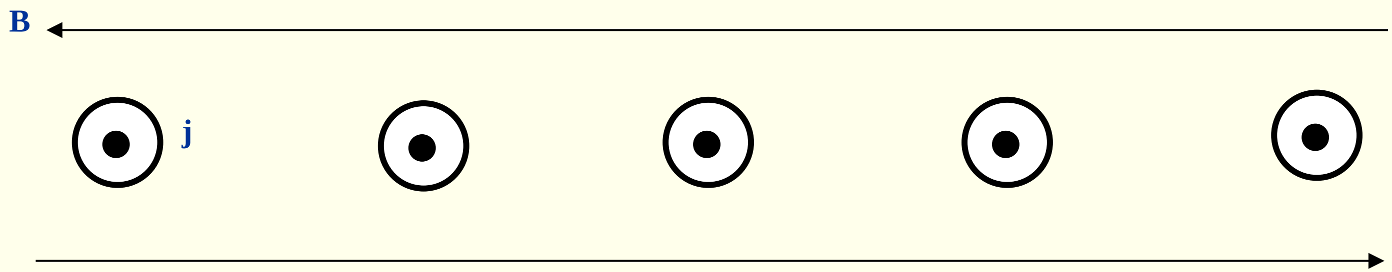
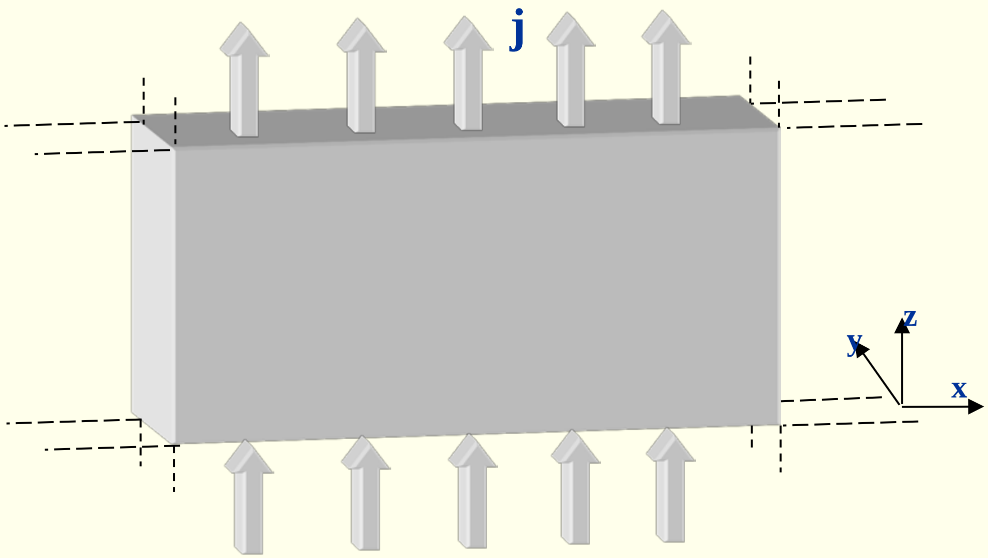


The closer you place the line currents, the more the magnetic fields between the line currents will cancel

Current sheet approximation and Ampére's law



$$\left(\frac{\partial B_z}{\partial y} - \frac{\partial B_y}{\partial z},\ \frac{\partial B_x}{\partial z} - \frac{\partial B_z}{\partial x},\ \frac{\partial B_y}{\partial x} - \frac{\partial B_x}{\partial y} \right) = \mu_0 \left(j_x,\ j_y,\ j_z \right)$$

But $\frac{\partial}{\partial x} = 0$ and $\frac{\partial}{\partial z} = 0$

$$\left(\frac{\partial B_z}{\partial y},\ 0,\ -\frac{\partial B_x}{\partial y} \right) = \mu_0 \left(0,\ 0,\ j_z \right)$$

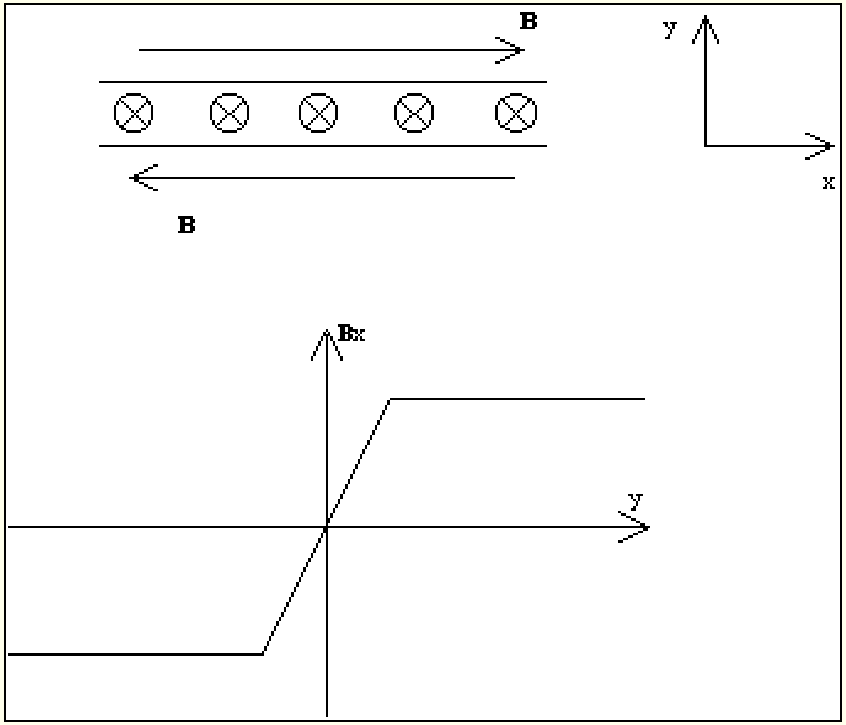
eller

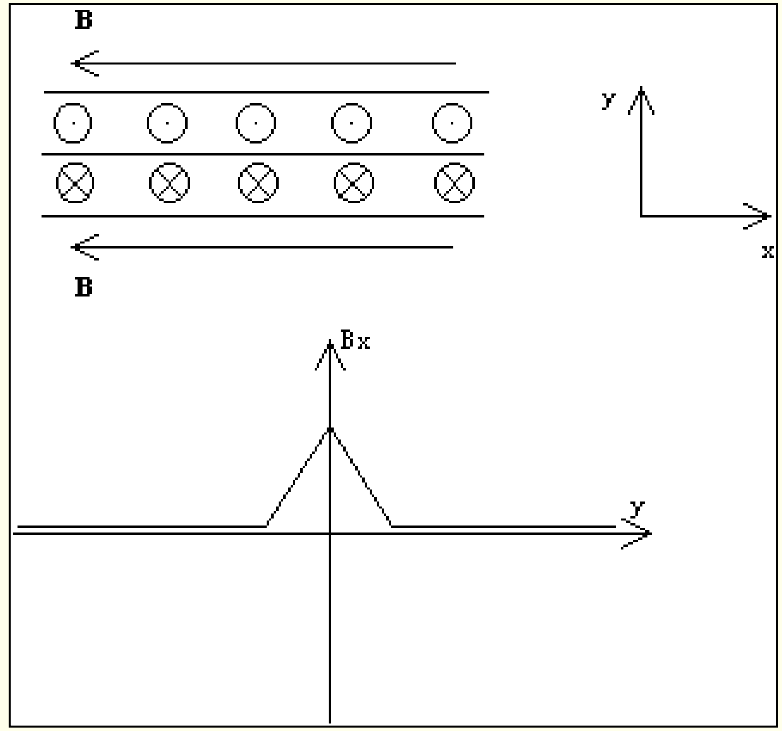
Ampére's law (no time dependence):

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

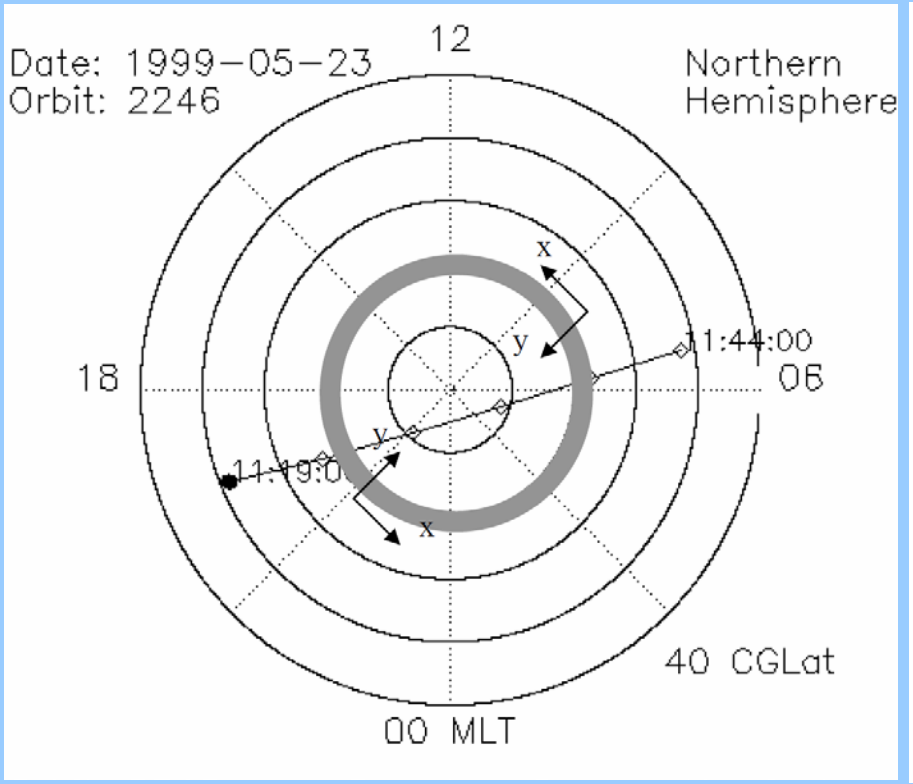
$$j_z = -\frac{1}{\mu_0} \frac{\partial B_x}{\partial y}$$

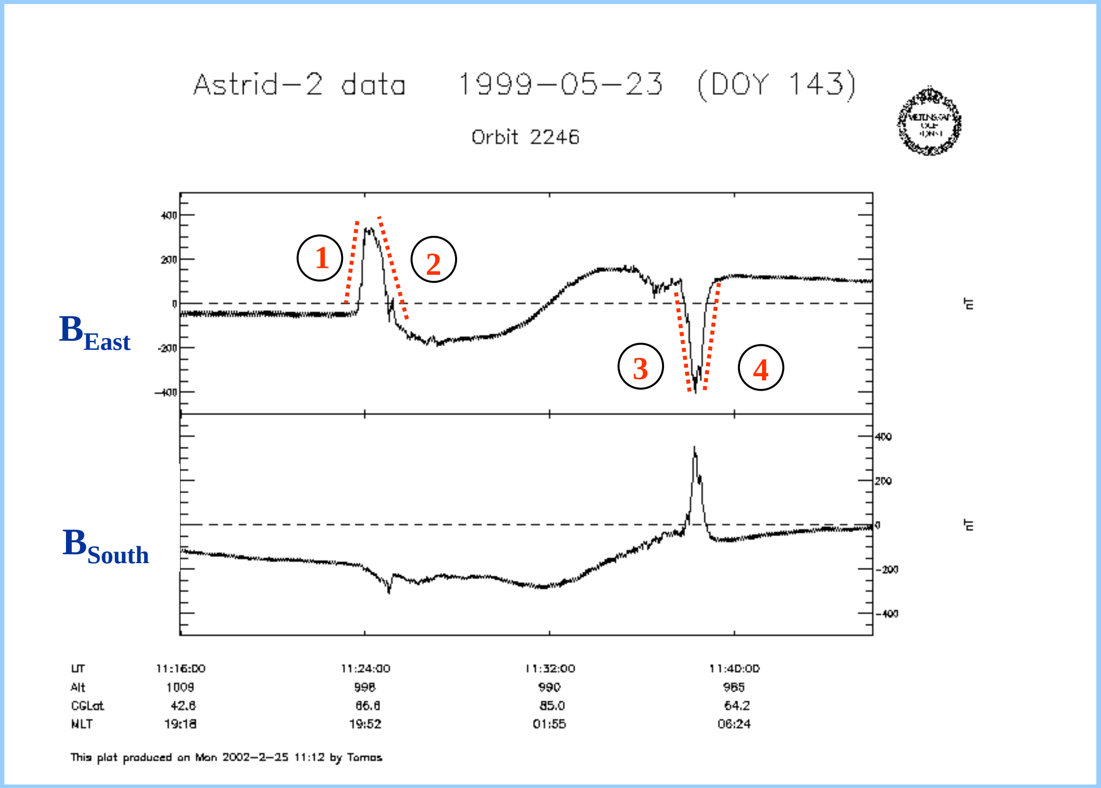
Current sheet - example





$$j_z = -\frac{1}{\mu_0}\frac{\partial B_x}{\partial y}$$



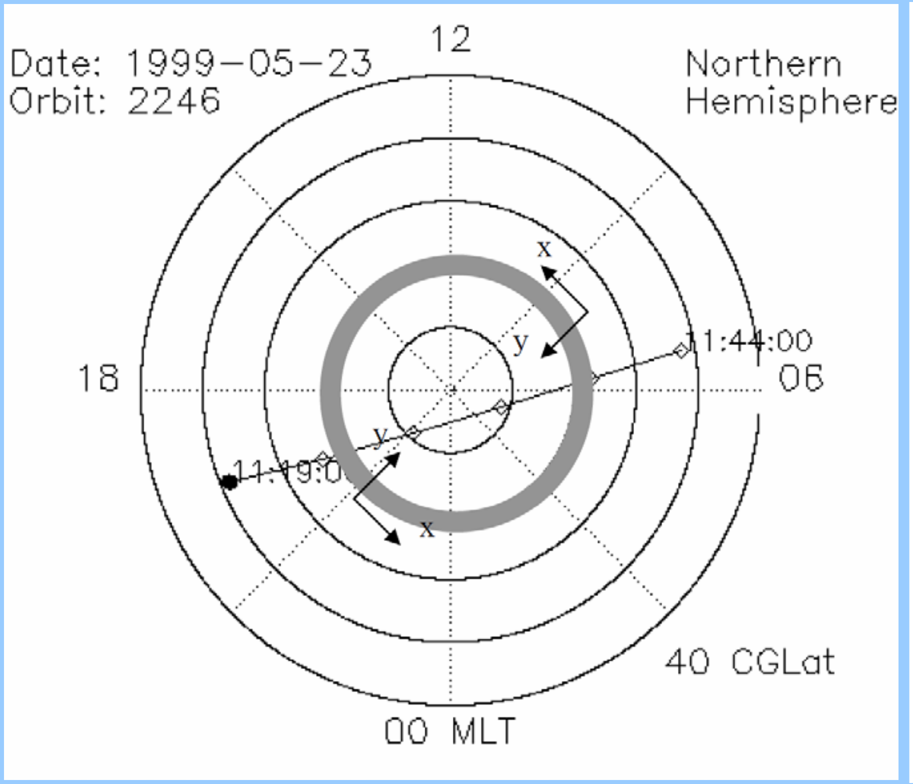


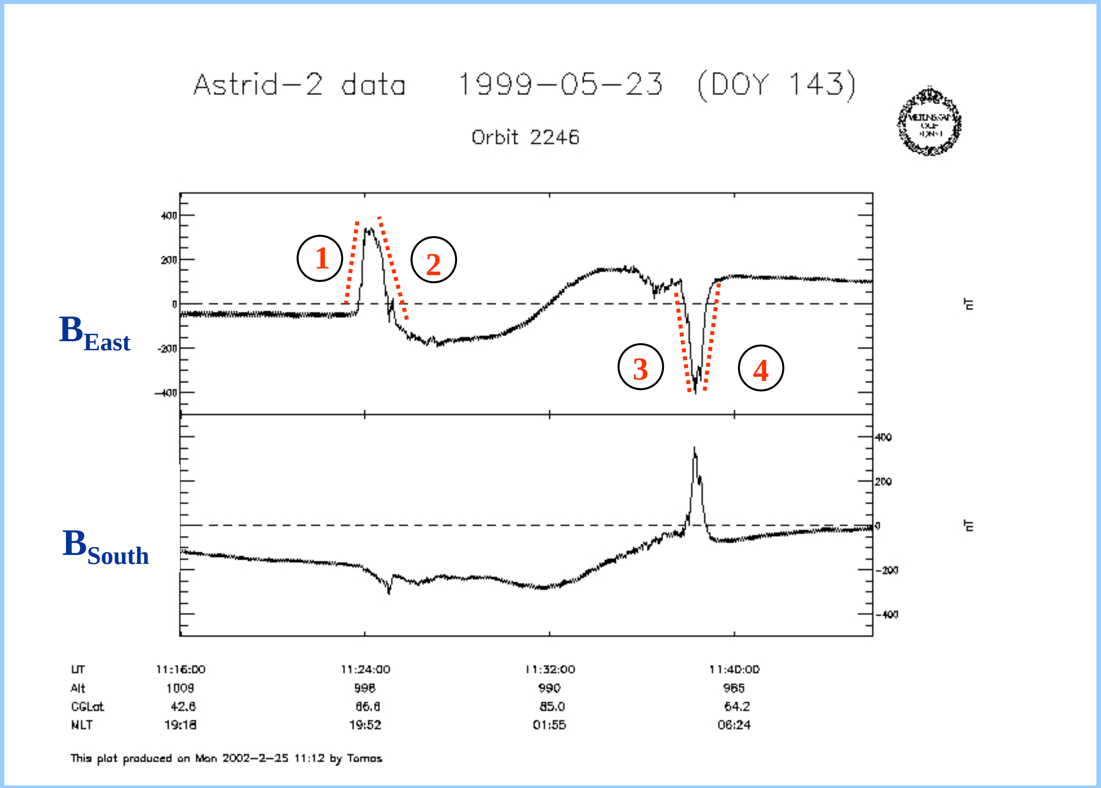
$$j_z = -\frac{1}{\mu_0}\frac{\partial B_x}{\partial y}$$

What is the direction of the current in current sheet 1?

Blue — Into the ionosphere

Red — Out of the ionosphere





What is the direction of the current in current sheet 1?

$$j_z = -\frac{1}{\mu_0}\frac{\partial B_x}{\partial y}$$

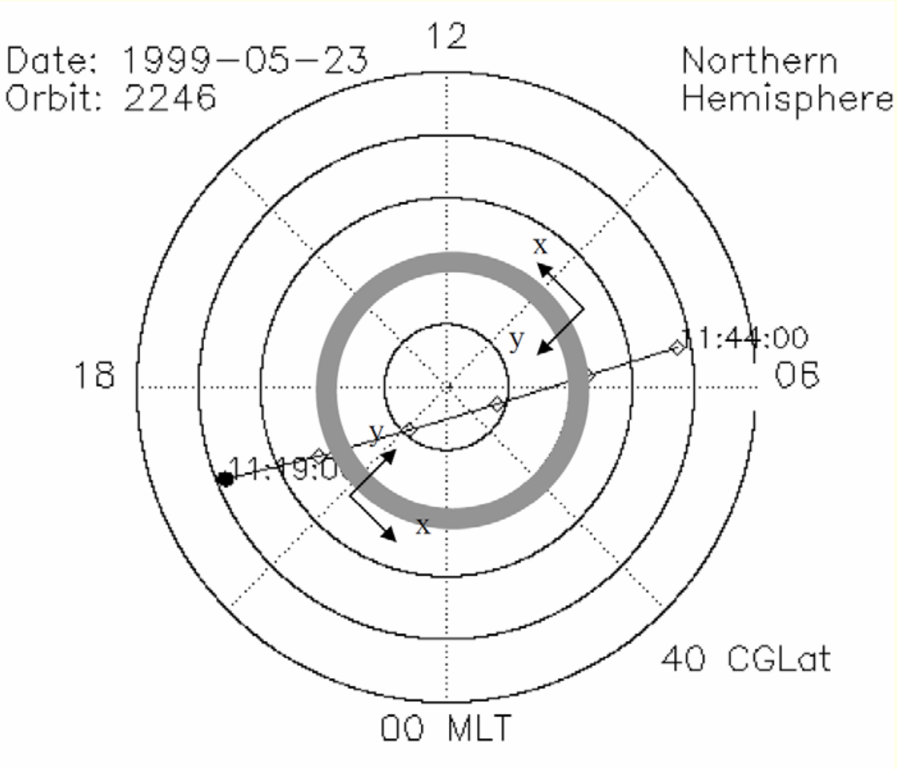
$$\frac{\partial B_x}{\partial y} = \frac{\partial B_{East}}{\partial y} > 0$$

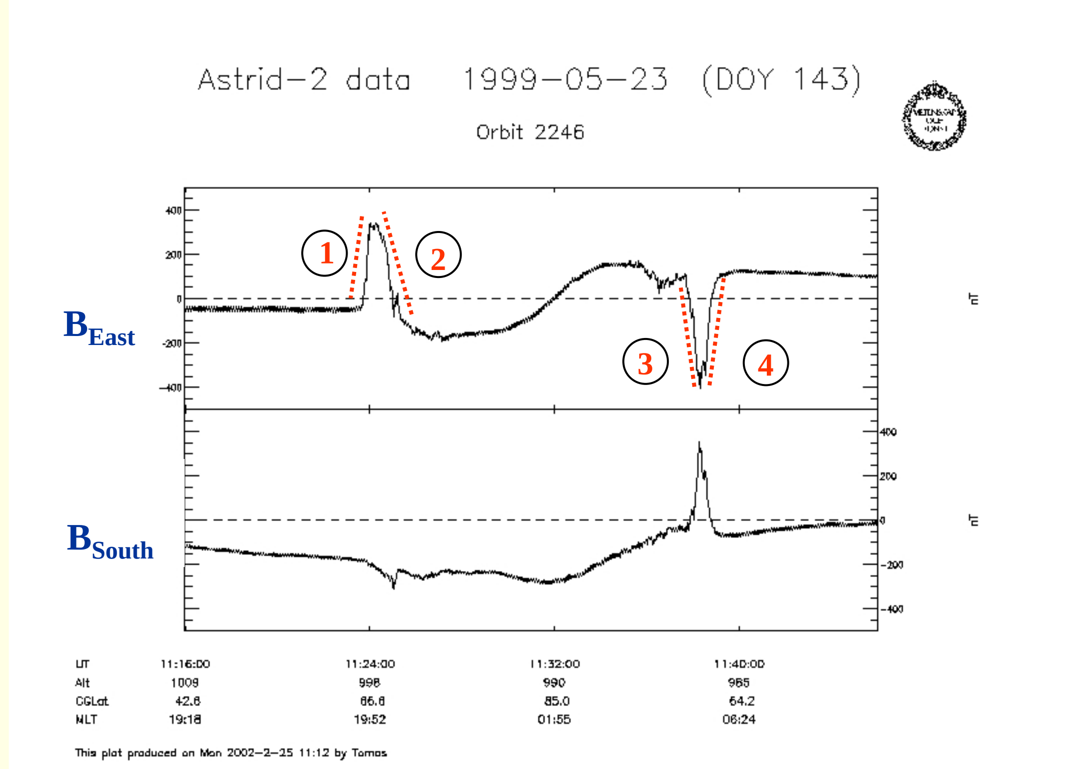
$$\Rightarrow$$

$$j_z < 0$$

Blue

Into the ionosphere





$$j_z = -\frac{1}{\mu_0}\frac{\partial B_x}{\partial y}$$

1) $\frac{\partial B_x}{\partial y} > 0 \quad \Rightarrow \quad j_z < 0$ Into the ionosphere

2) $\frac{\partial B_x}{\partial y} < 0 \quad \Rightarrow \quad j_z > 0$ Out of the ionosphere

3) $\frac{\partial B_x}{\partial y} > 0 \quad \Rightarrow \quad j_z < 0$ Into the ionosphere

4) $\frac{\partial B_x}{\partial y} < 0 \quad \Rightarrow \quad j_z > 0$ Out of the ionosphere

Birkeland currents in the auroral oval