Introduction to Solar System Physics

Lecture course by
scientists from the Max Planck Institute for Solar System Research in Katlenburg-Lindau

summer semester 2009

Seminarraum Astrophysik, Mondays 10:15 - 11:45

Slides are found in:
http://www.solar-system-school.de/lectures.html

Topics and Lecturers

1.	Overview on the solar system	U. Christensen	20.04.
2.	Planetary atmospheres	D. Titov	04.05.
3.	Small bodies	H. Krüger	11.05.
4.	Planetary magnetospheres	N. Krupp	18.05.
5.	Planetary interiors	U. Christensen	25.05.
6.	Formation of planetary systems	D. Schmitt	08.06.
7.	Solar corona and solar wind	E. Marsch	15.06.
8.	Solar – terrestrial relations	J. Büchner	22.06.
9.	Solar interior and helioseismology	L. Gizon	29.06.
10.	Photosphere and Chromosphere	S. Solanki	06.07.
11.	Solar convection zone and magnetic field	M. Schüssler	13.07.

Credit points (3 ECTS) in the batchelor / master curriculum can be obtained after a written test at the end of the semester.

8. Solar-Terrestrial Relations

- Climate – Weather – Space Weather
- From Sun to Earth
- Solar wind and magnetosphere
- Physics of the magnetosphere
- Formation of the ionosphere
- Ionospheric currents and Aurorae
- Influence on men and satellites in space
- Space Weather phenomena Earth

The first glimpse

MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

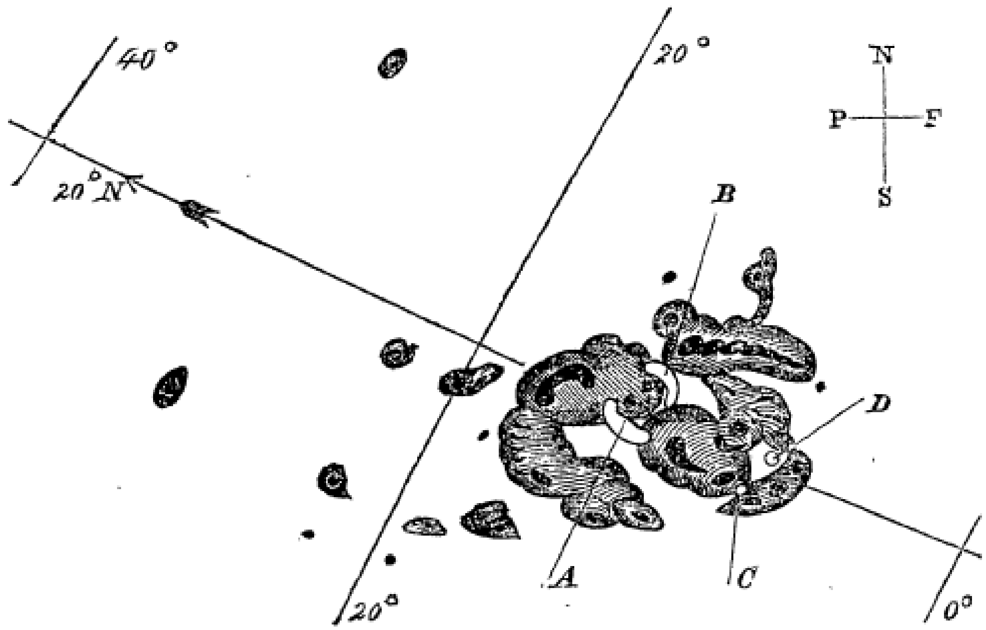
Vol. XX. *Nov.* 11, 1859. No. 1.

It has been very gratifying to me to learn that our friend Mr. Hodgson chanced to be observing the sun at his house at Highgate on the same day, and to hear that he was a witness of what he also considered a very remarkable phenomenon. I have carefully avoided exchanging any information with that gentleman, that any value which the accounts may possess may be increased by their entire independence.

(Mr. Carrington exhibited at the November Meeting of the Society a complete diagram of the disk of the sun at the time, and copies of the photographic records of the variations of the three magnetic elements, as obtained at Kew, and pointed out that a moderate but very marked disturbance took place at about 11^{h} 20^{m} A.M., Sept. 1st, of short duration; and that towards four hours after midnight there commenced a great magnetic storm, which subsequent accounts established to have been as considerable in the southern as in the northern hemisphere. While the contemporary occurrence may deserve noting, he would not have it supposed that he even leans towards hastily connecting them. "One swallow does not make a summer.")

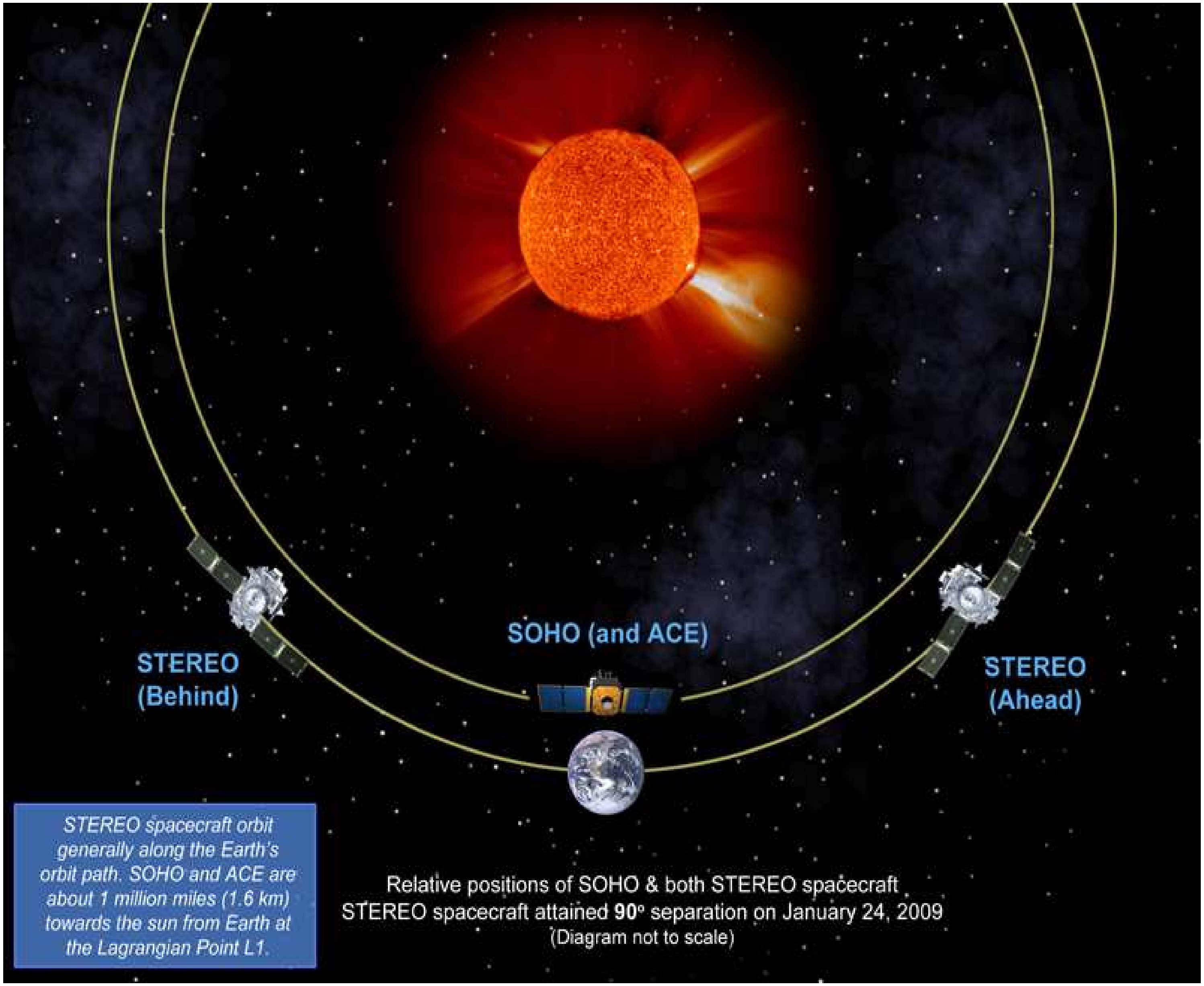
Description of a Singular Appearance seen in the Sun on September 1, 1859. By R. C. Carrington, Esq.

While engaged in the forenoon of Thursday, Sept. 1, in taking my customary observation of the forms and positions of the solar spots, an appearance was witnessed which I believe to be exceedingly rare. The image of the sun's disk was, as usual with me, projected on to a plate of glass coated with distemper of a pale straw colour, and at a distance and under a power which presented a picture of about 11 inches diameter. I had secured diagrams of all the groups and detached spots, and was engaged at the time in counting from a chronometer and recording the contacts of the spots with the cross-wires used in the observation, when within the area of the great north group (the size of which had previously excited general remark), two patches of intensely bright and white light broke out, in the positions indicated in the appended diagram by the letters A and B, and of the forms of the spaces left white. My



first impression was that by some chance a ray of light had penetrated a hole in the screen attached to the object-glass, by

Recent s/c observations of the Sun



Missons / launch date

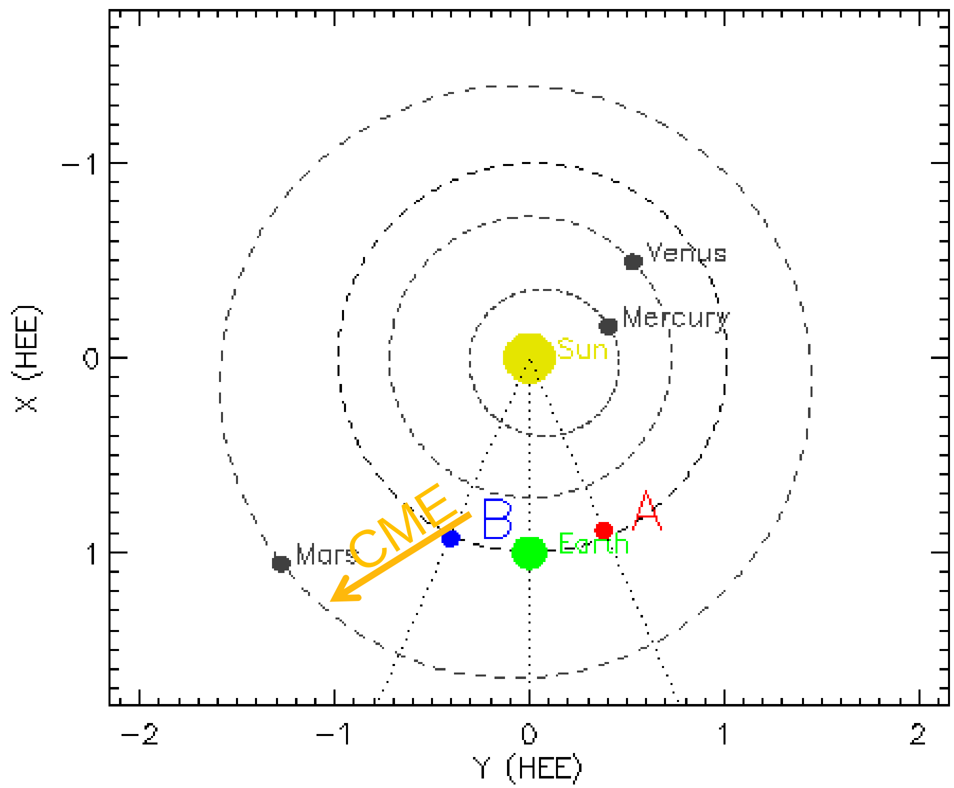
SOHO / Dec 1995

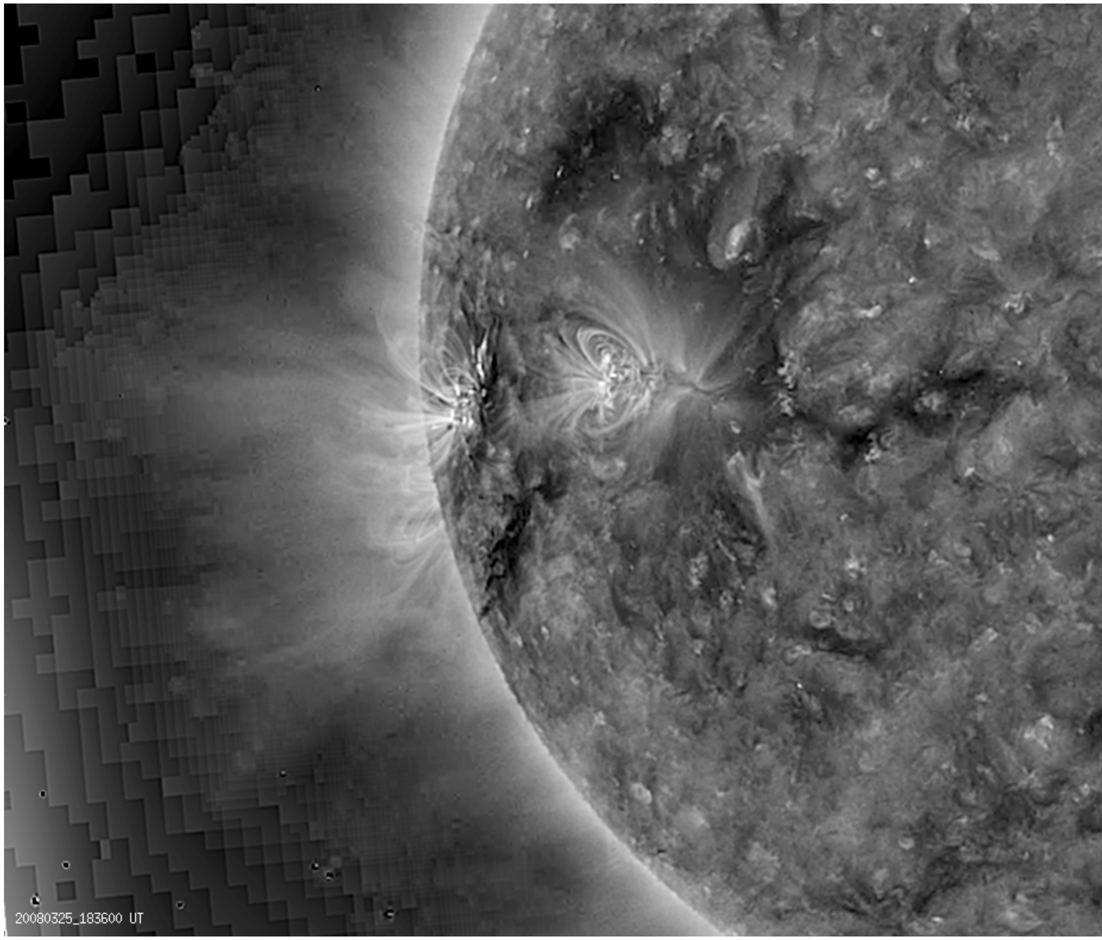
ACE / Aug 1997

HINODE / Sep 2006

STEREO / Oct 2006

CME observation by STEREO B / A



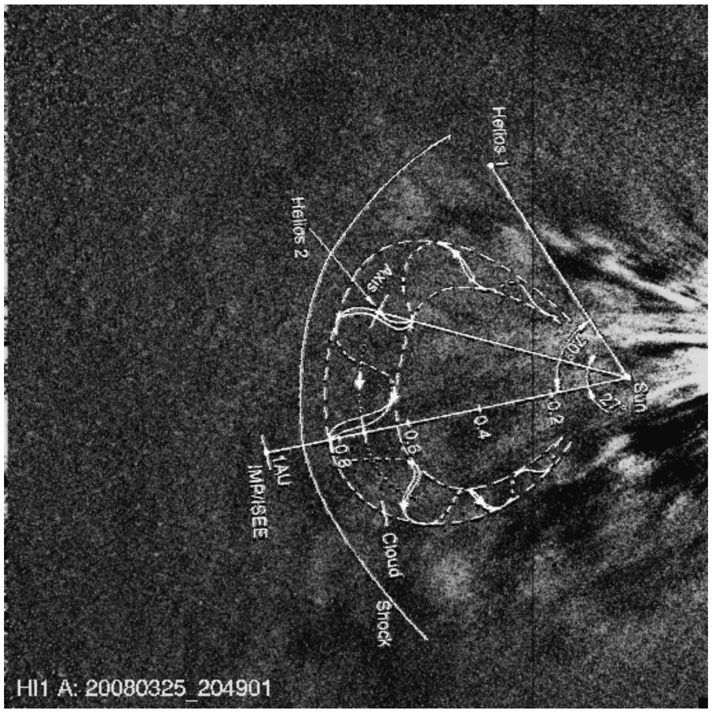


Situation on 25.8.2008: Δφ=47°, Δt=75s

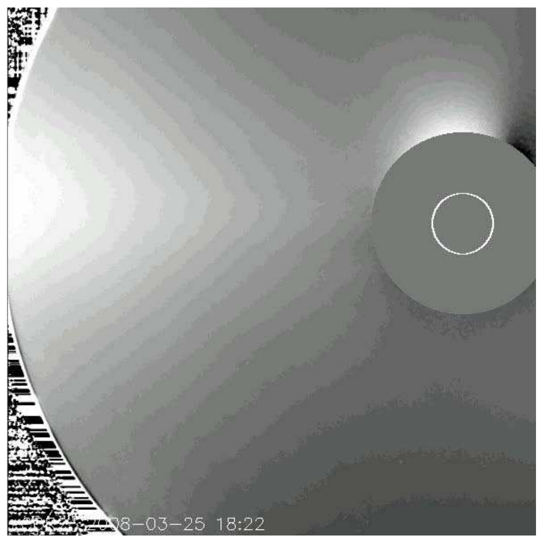
EUVI A (171 Å): CME first 7min [Wavelet analysis by Stenborg & Vourlidas, NRL]

The evolution of the CME launched 25.8.2008 as seen by SECCHI A

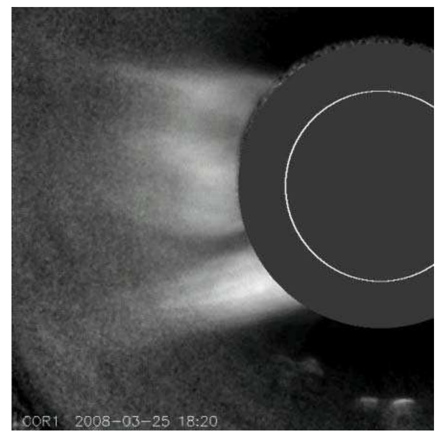
HI 1



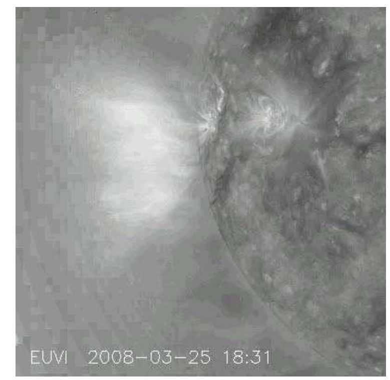
COR 2



COR 1

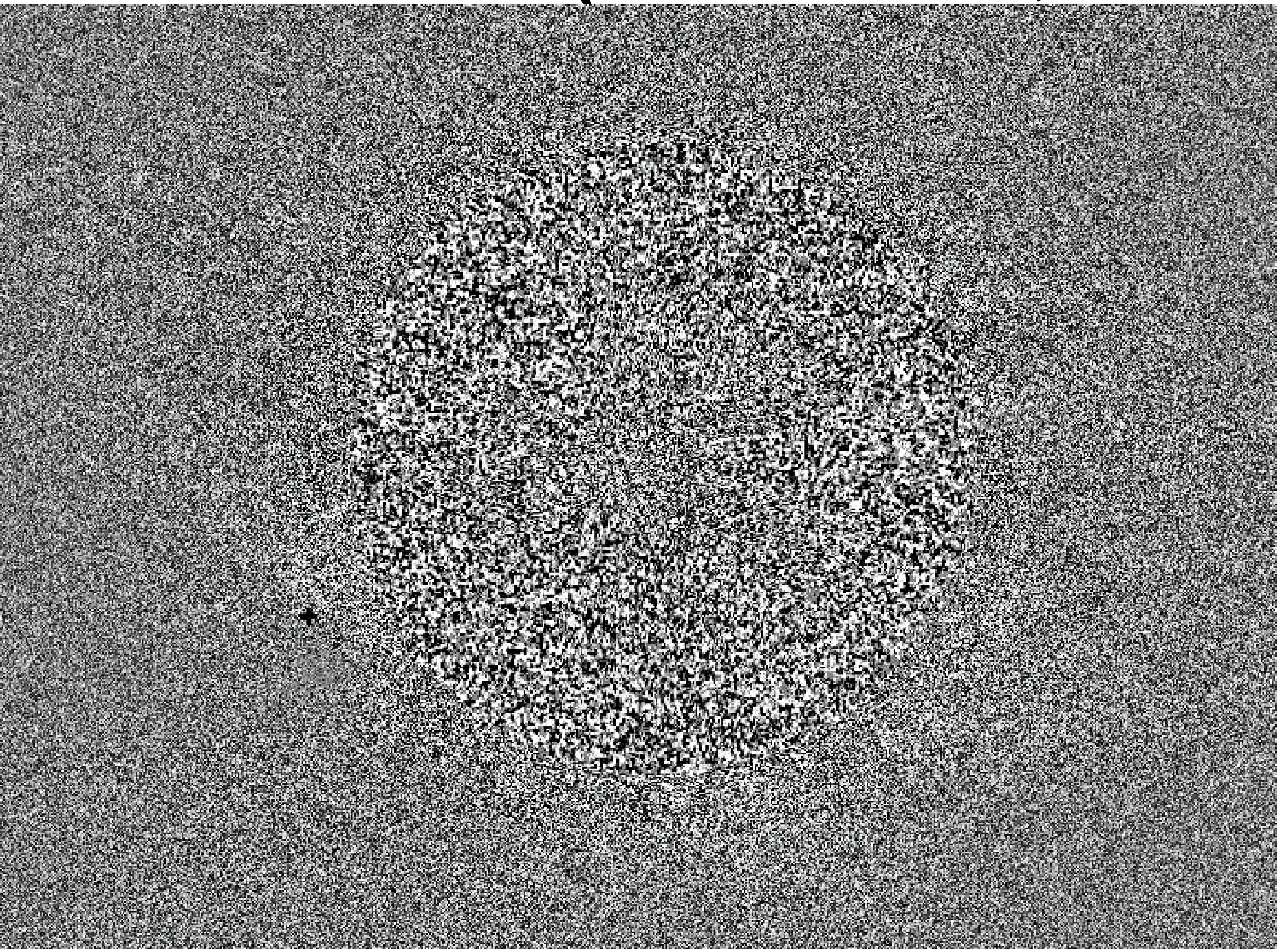


EUVI 171 Å



courtesy: V. Bothmer

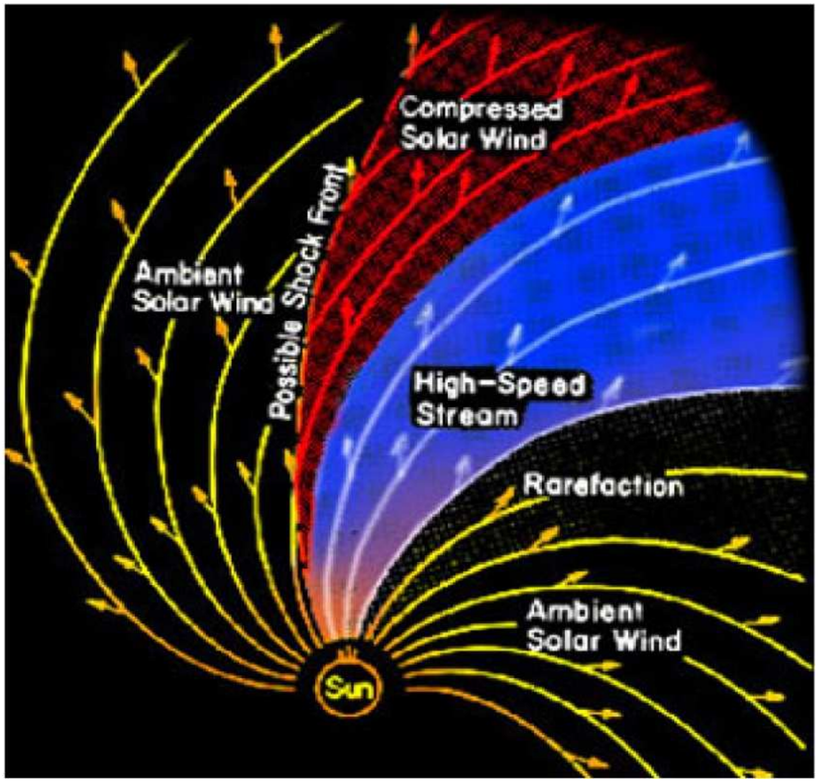
First succesfull CME-tracking from Sun to Earth (SECCHI HI, STEREO s/c A)

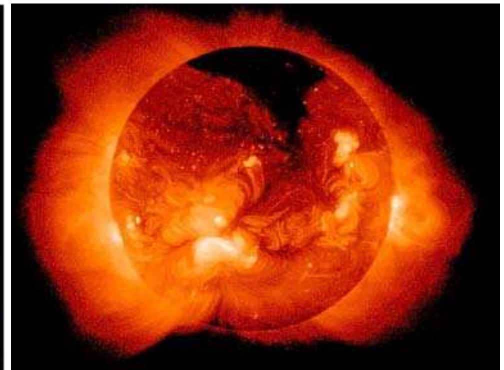


SECCHI- HI (Heliospheric Imager, Spectral range: 400-1000 nm) observation of February 6, 2008

courtesy: STEREO – SECCHI team

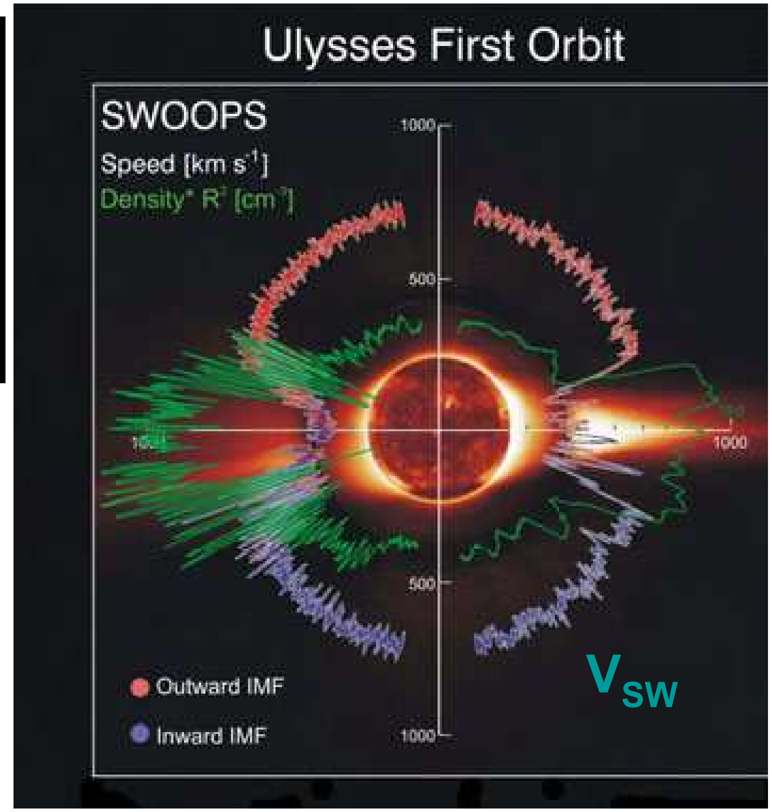
Tracing plasma from Sun to Earth





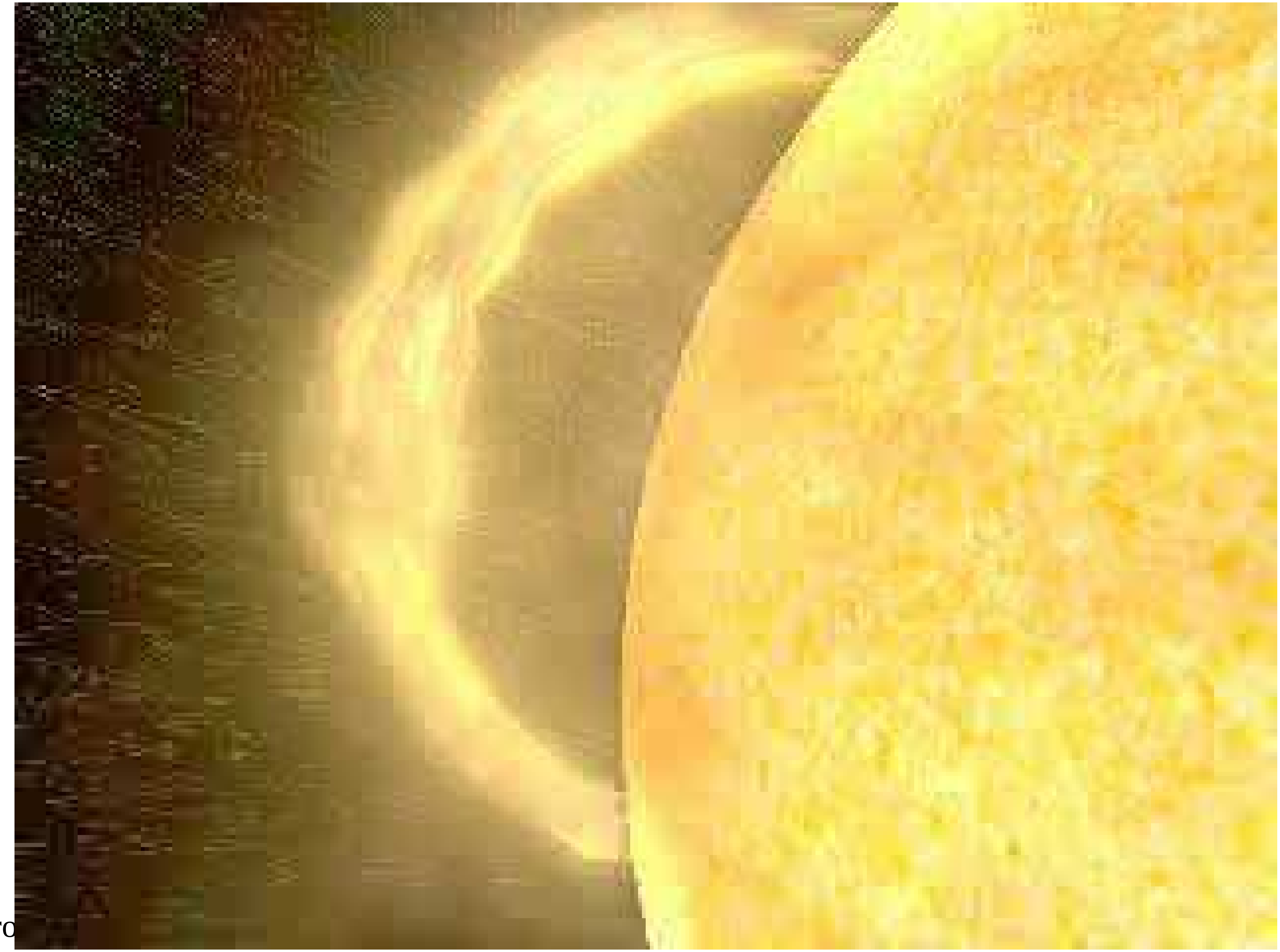
Yohkoh

Ulysses

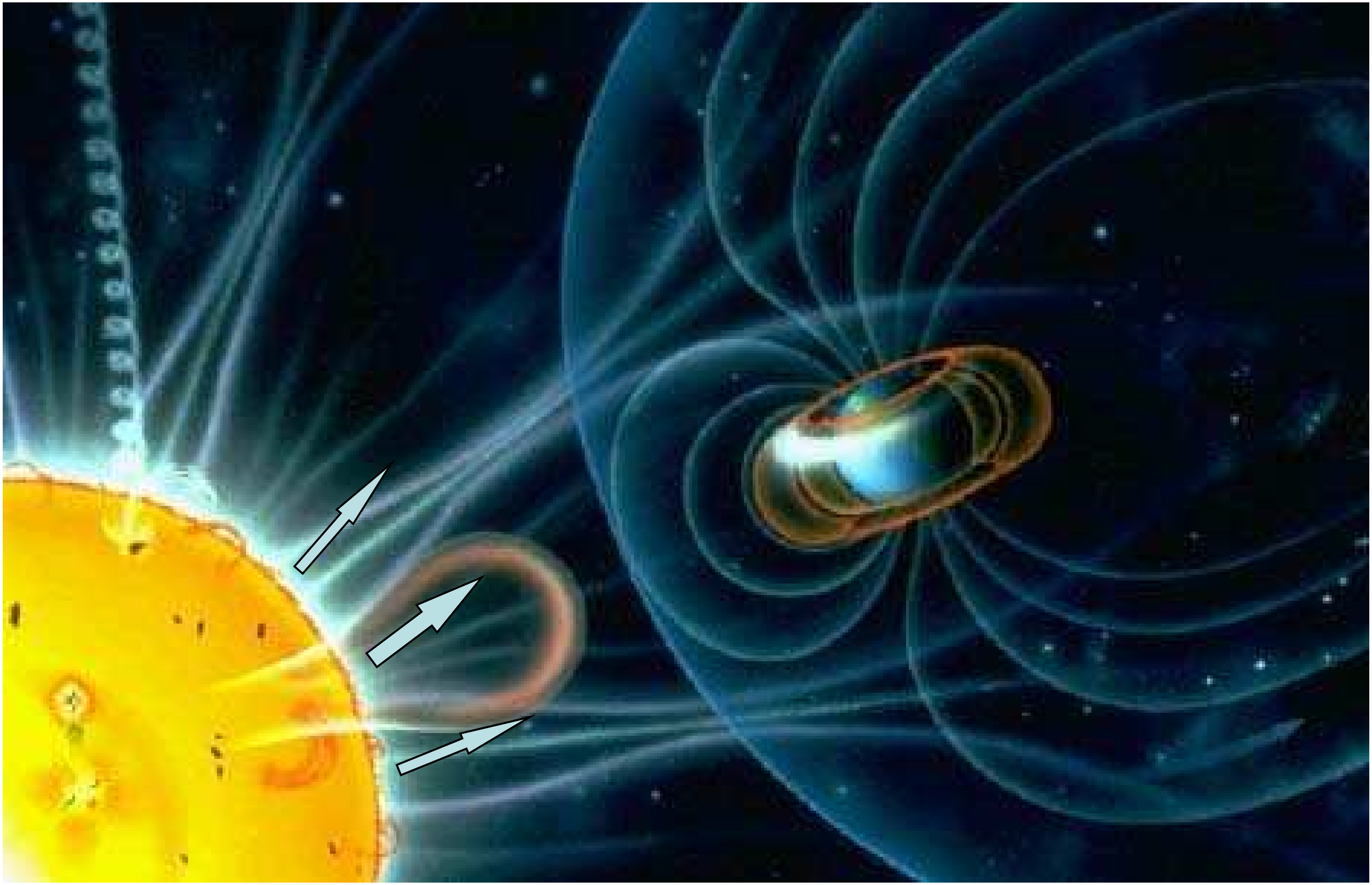


- **Slow solar wind: from regions of bright X-ray emissions / low rising solar magnetic field structures ?**
- **Fast solar wind: from coronal holes / “open” fields**
- **Interaction of the two: Compressional regions, shocks ...**

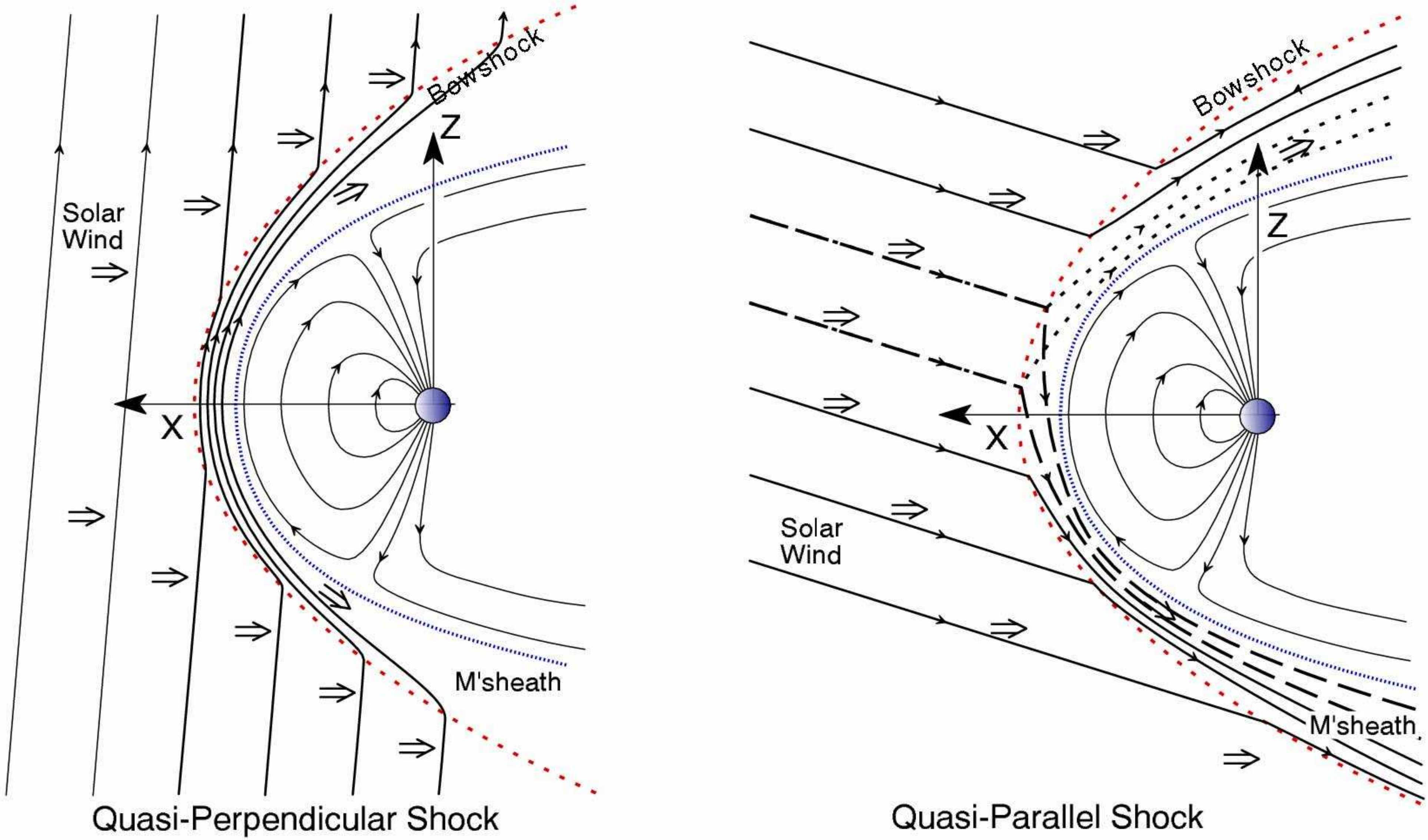
Consequences for the Earth



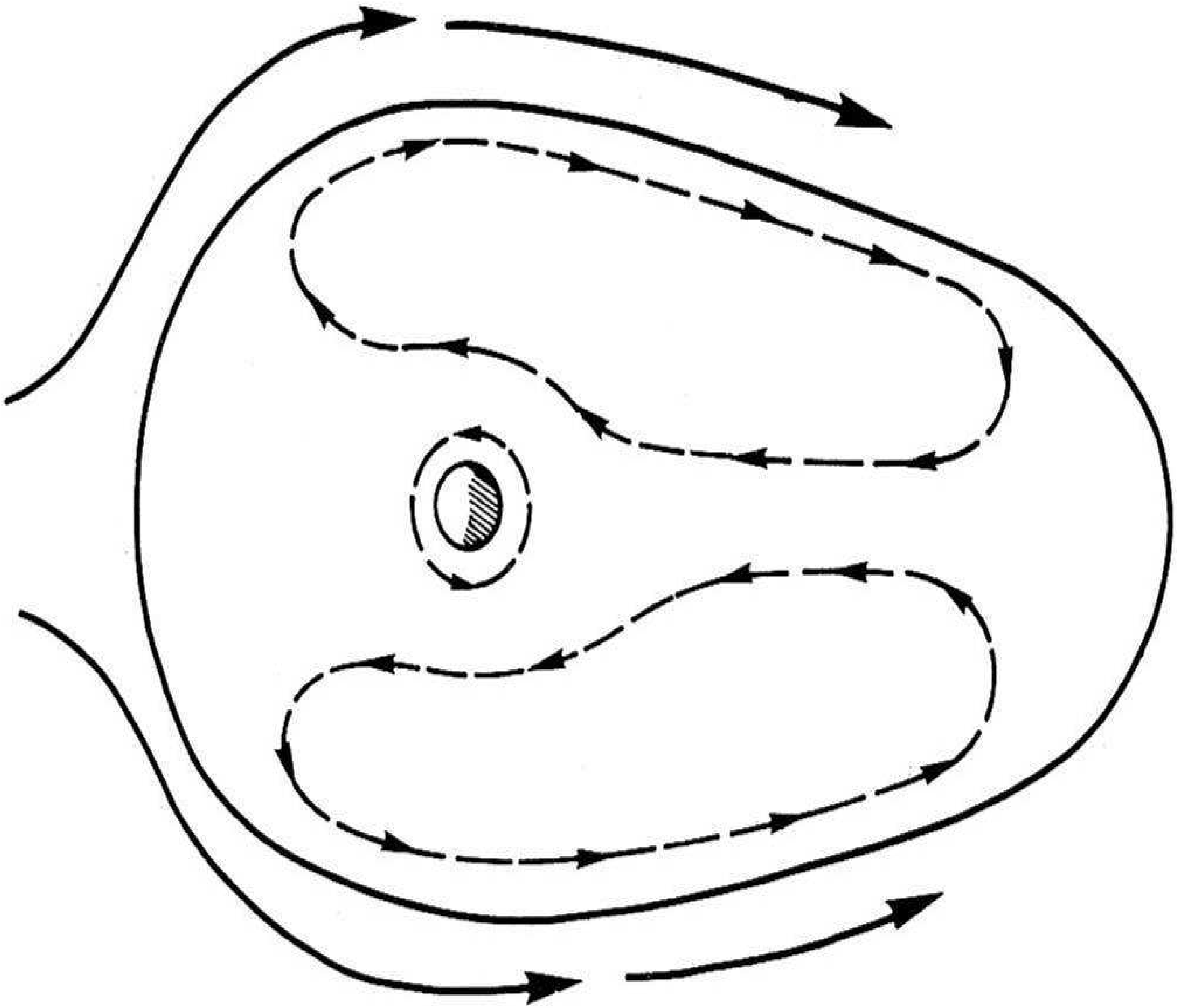
Magnetic structure near Earth



Bow shock (discovered in the 1960ies)

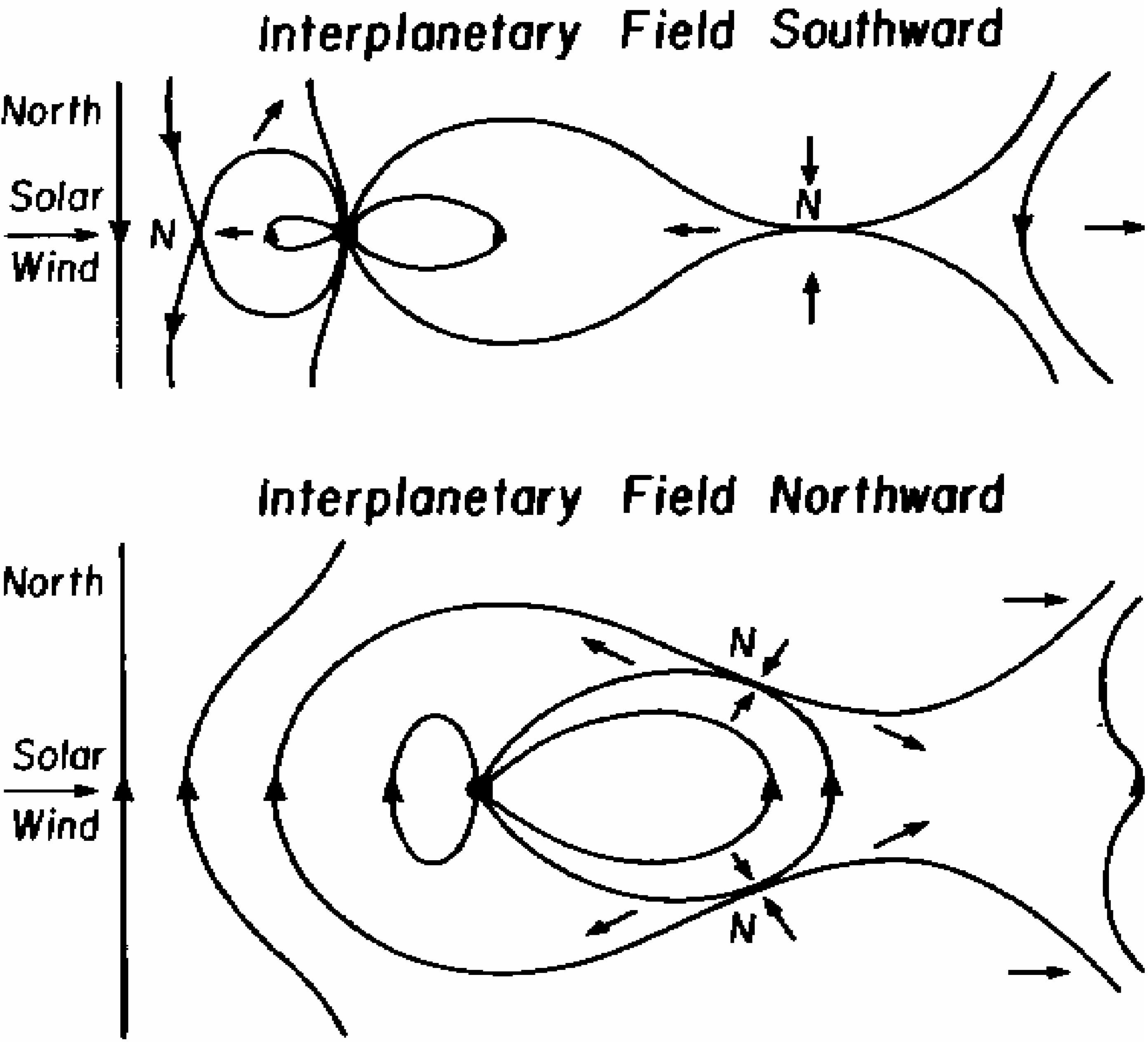


Partially open magnetosphere (1961)



Pattern of the plasma convection driven by viscous interaction between the solar wind with a the earth's magnetospheric plasma [Axford and Hines, 1961]

Open magnetosphere [Dungey,1961]

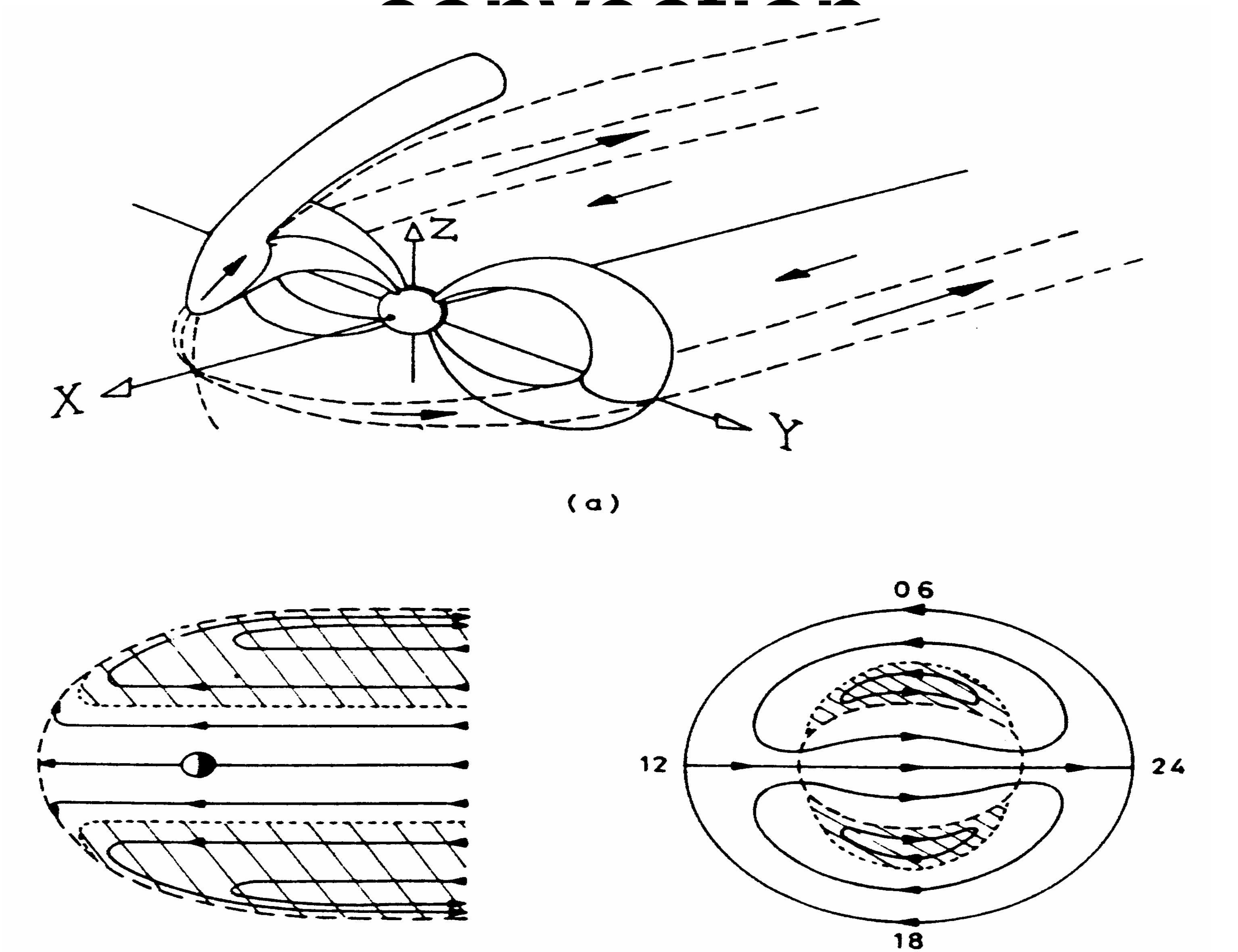


Two basic states:

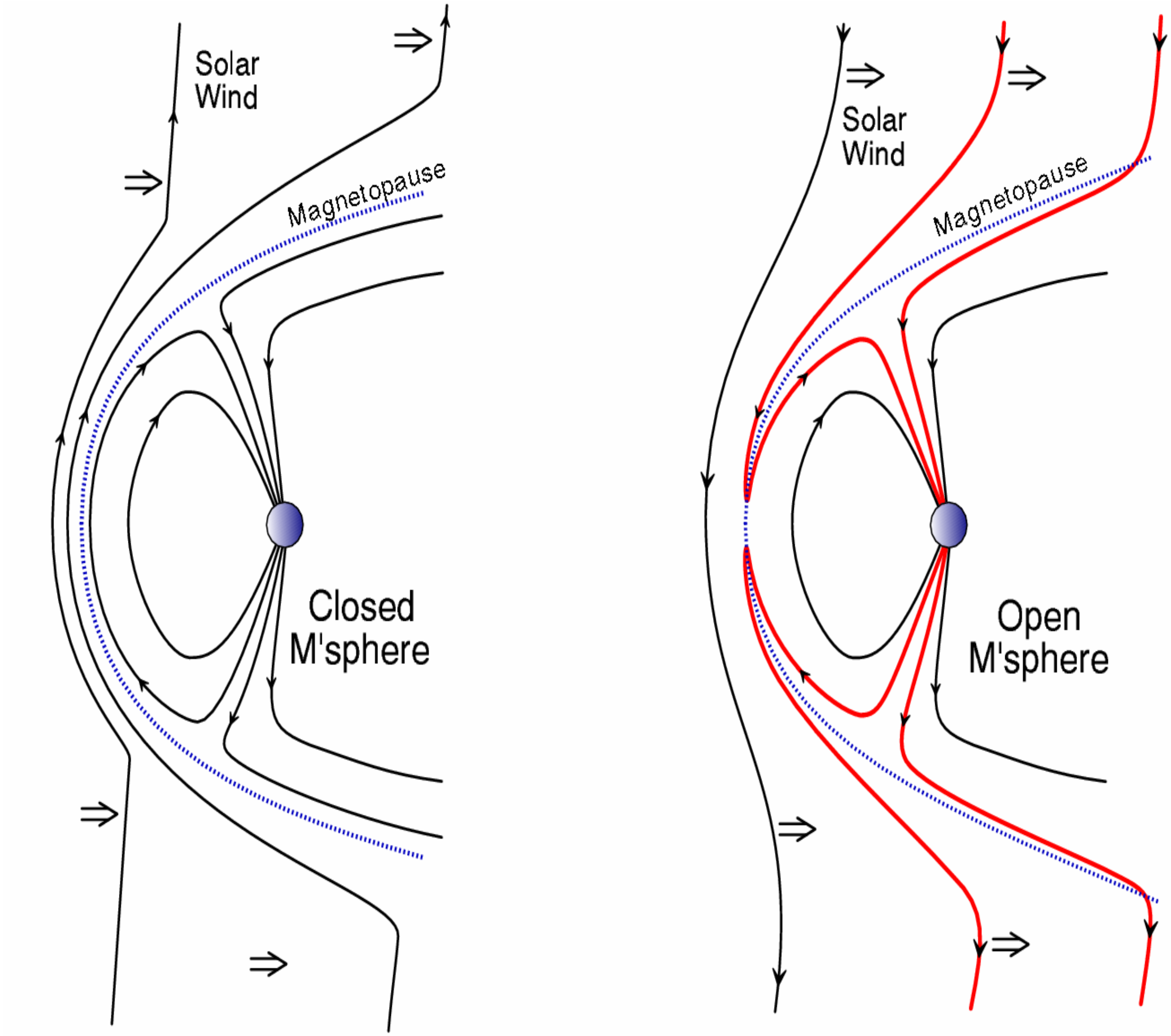
(A) Southward Interplanetary B-field -> strong dayside reconnection controls the magnetospheric convection

(B) Northward Interplanetary B-field -> reconnection only behind the cusps of the magnetosphere,

Today: Partially open magnetosphere, reconnection and convection



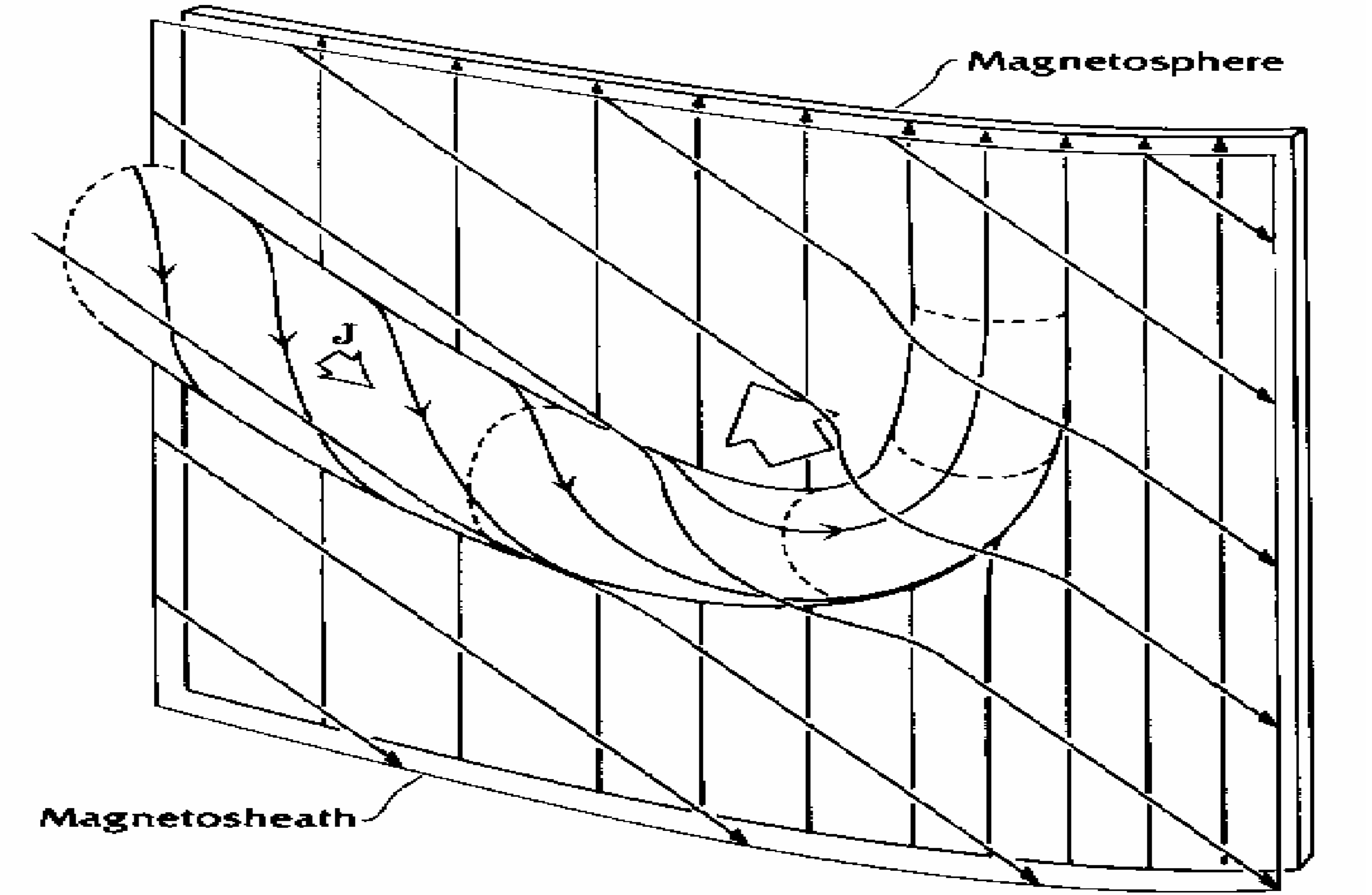
Magnetopause (Open and closed)



Left figure: “Closed” magnetosphere inside the blue dashed „magnetopause“

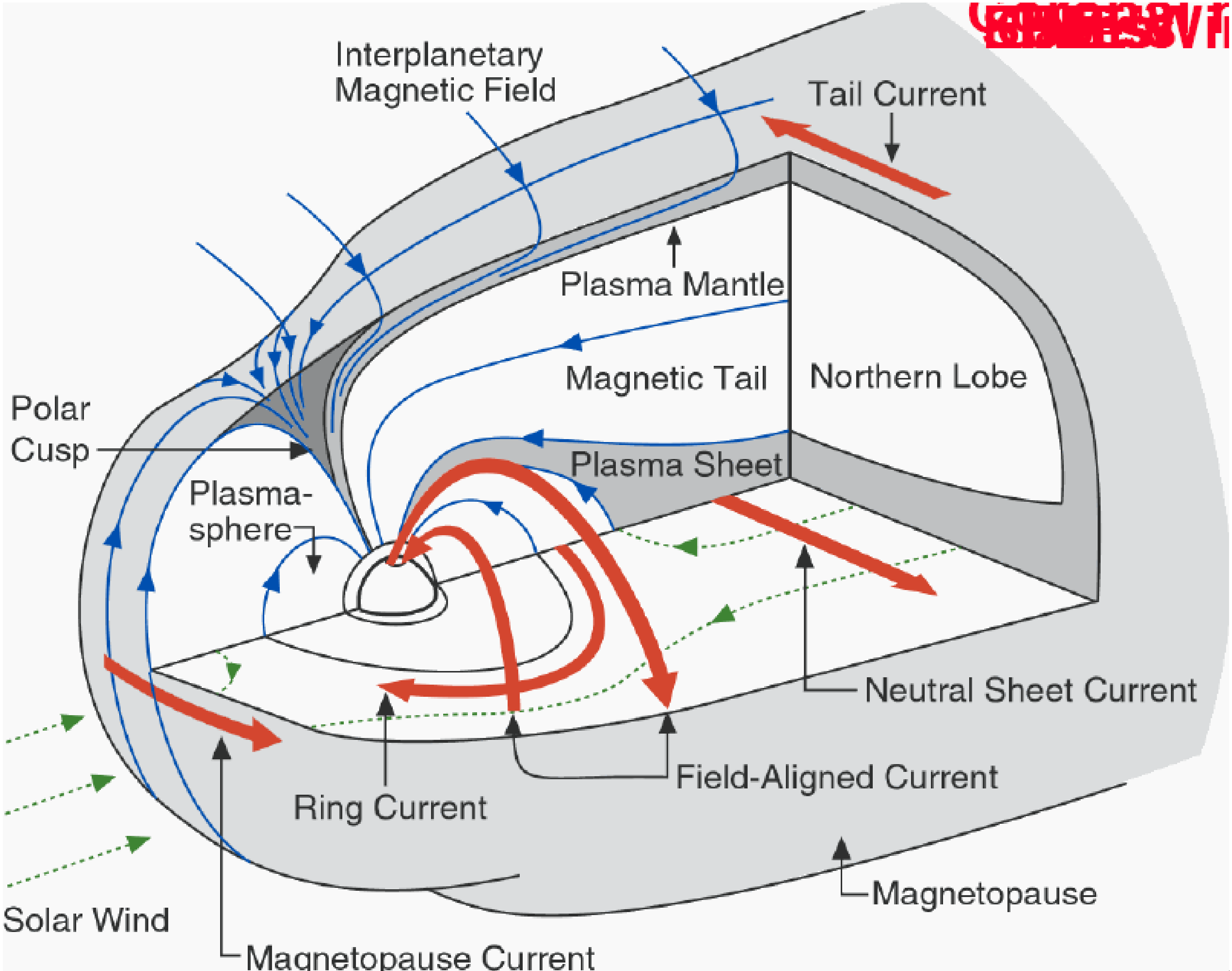
Right figure: Red: „Open“ magnetospheric field lines: Reconnection connects

Flux-transfer through magnetopause

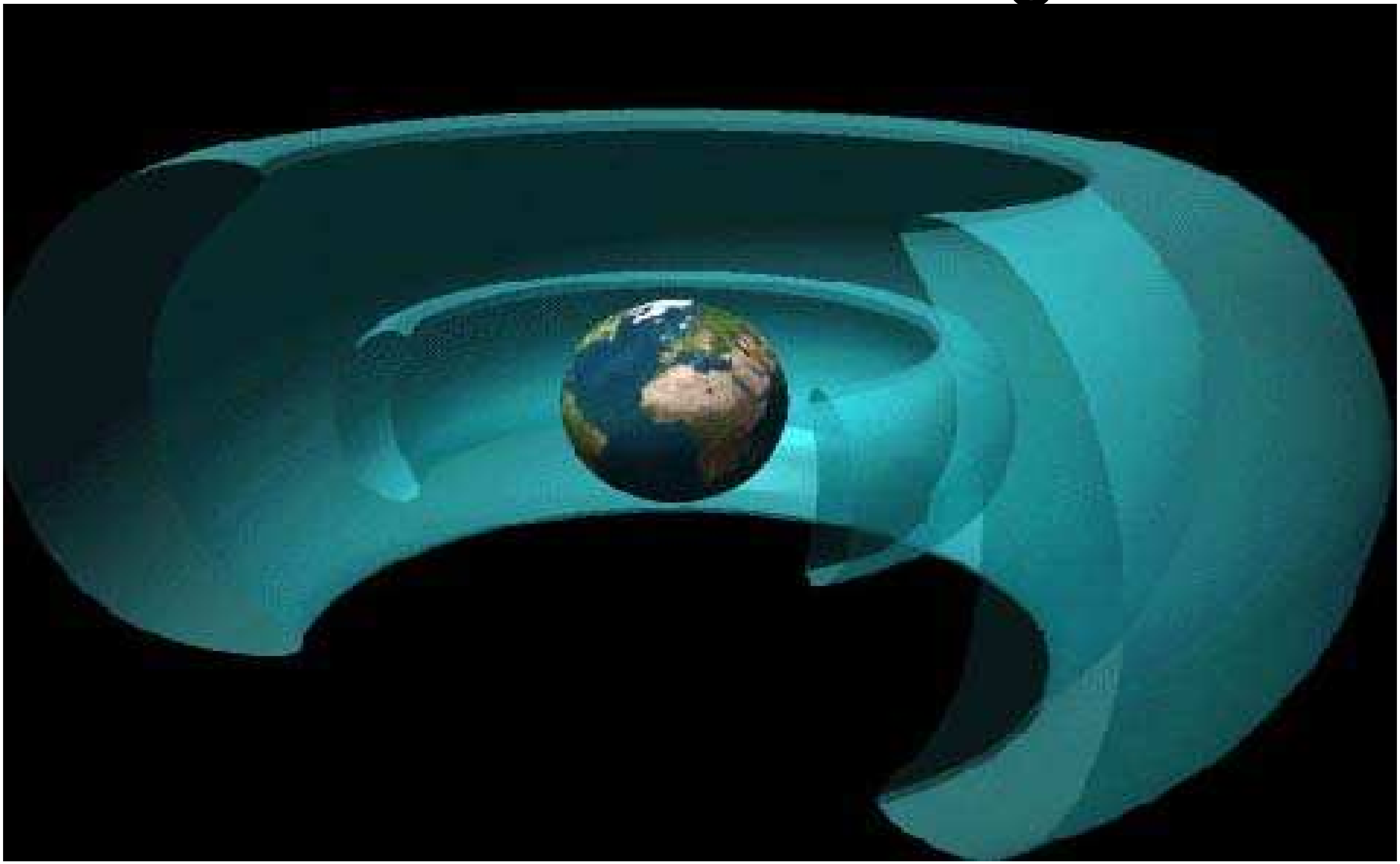


I

Magnetospheric current systems

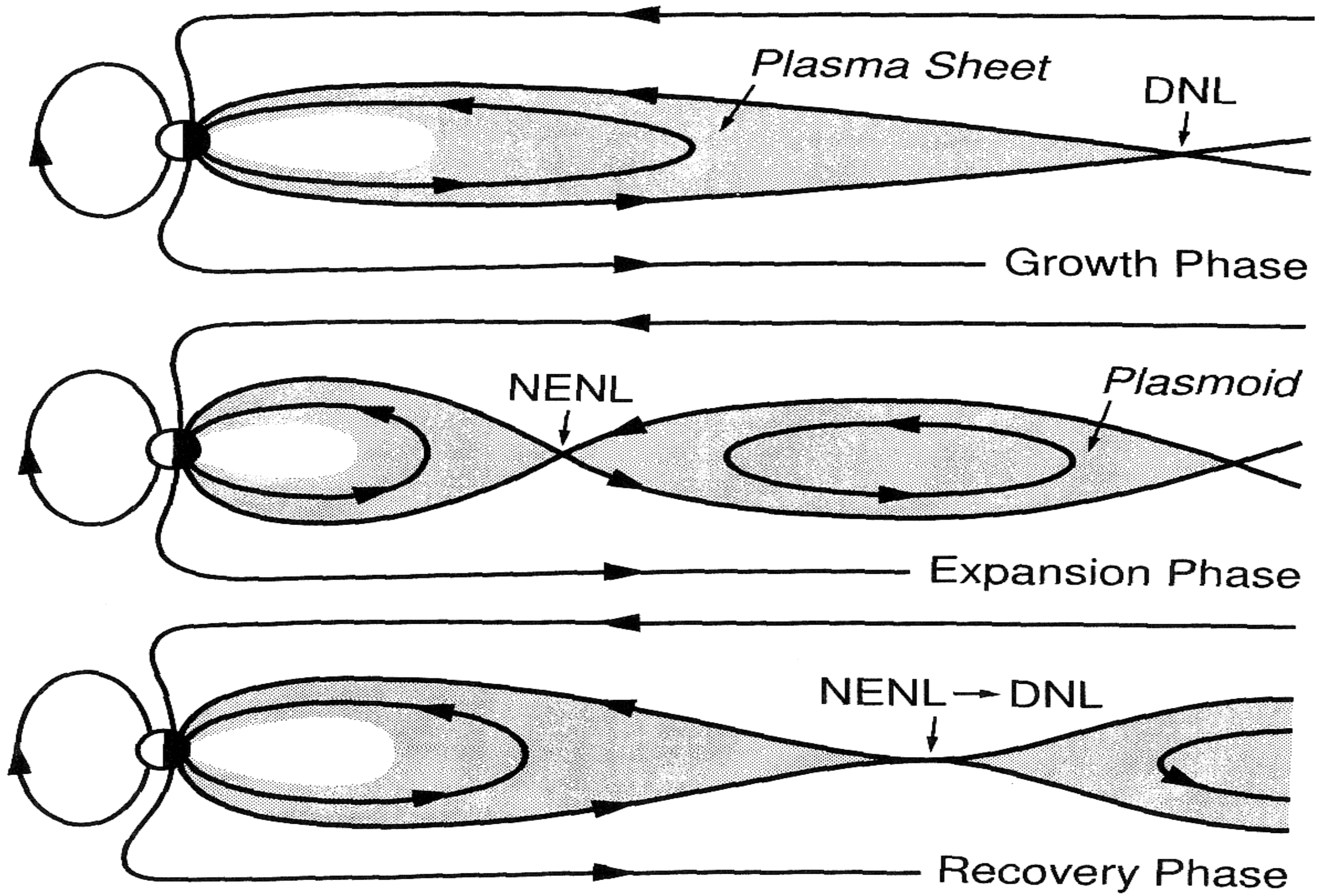


Radiation belts and ring current

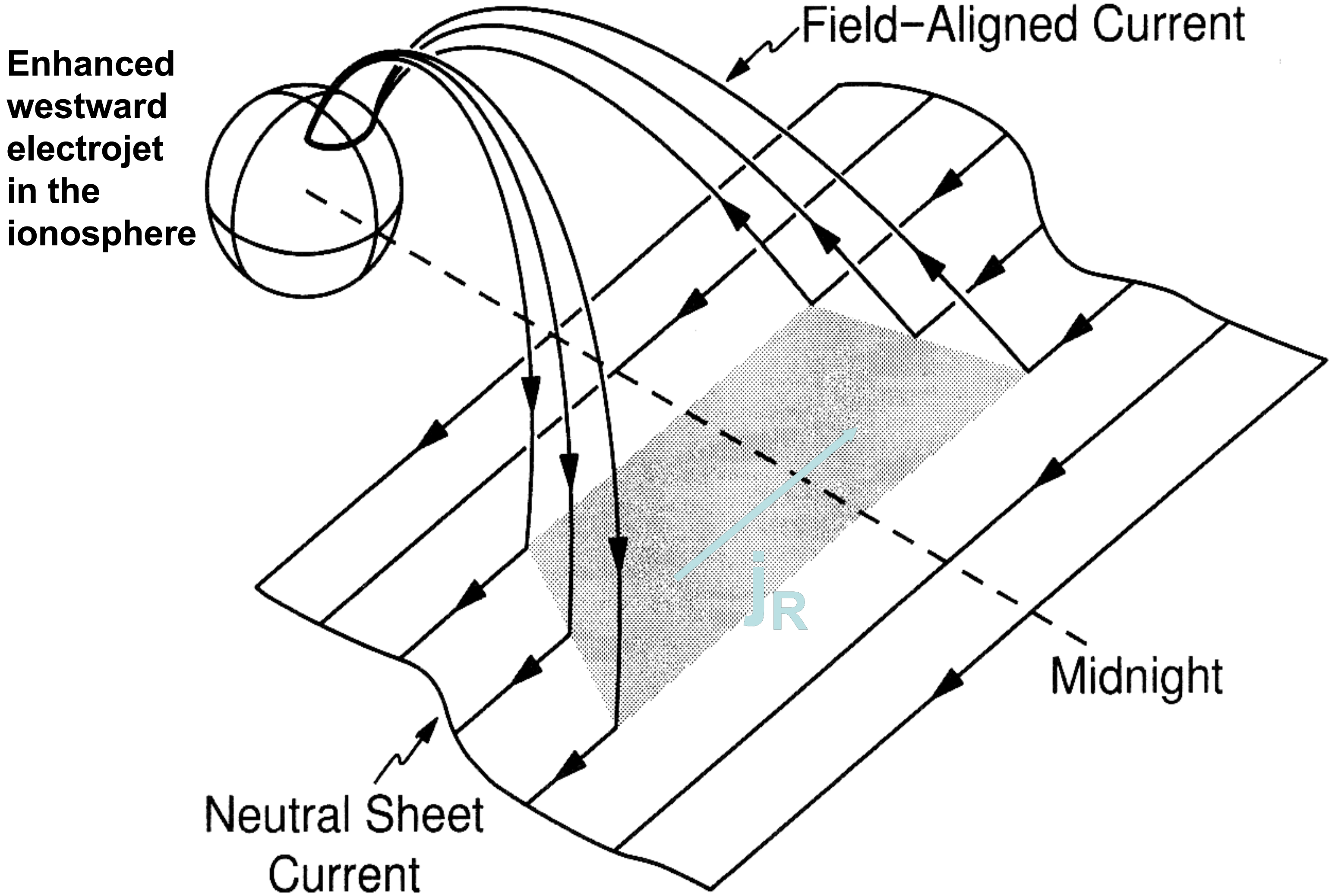


Discovery: 1958 by Explorer/van Allen: trapped energetic (keV – MeV) electrons, accelerated in the magnetosphere.

Substorms

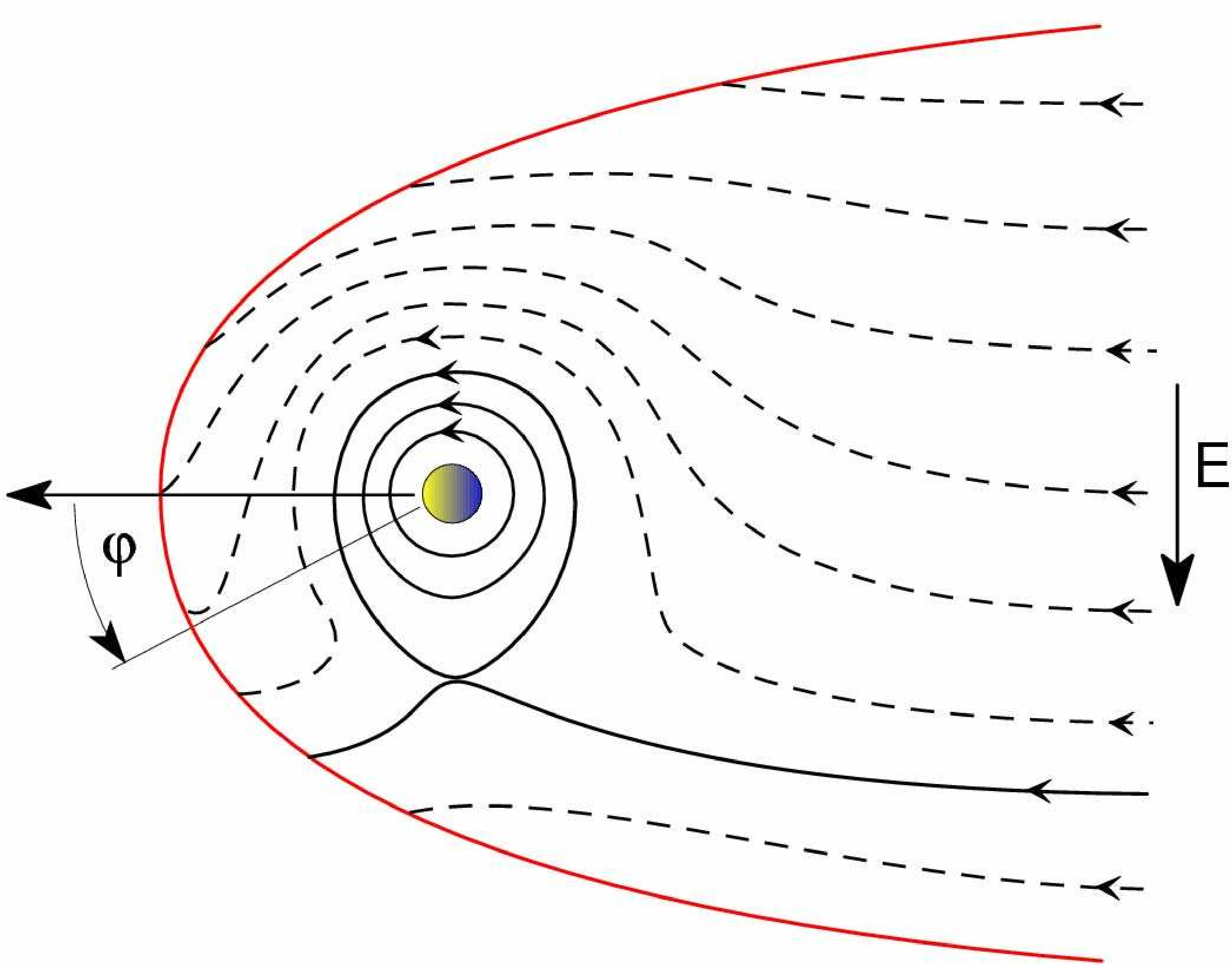

Plasma Sheet
DNL
Growth Phase
NENL
Plasmoid
Expansion Phase
NENL → DNL
Recovery Phase

The Substorm Current Wedge



Reference: R. L. McPherron, Magnetospheric substorms, Rev. Geophys. Space Phys., 1979.

Plasmasphere: Co-rotating plasma



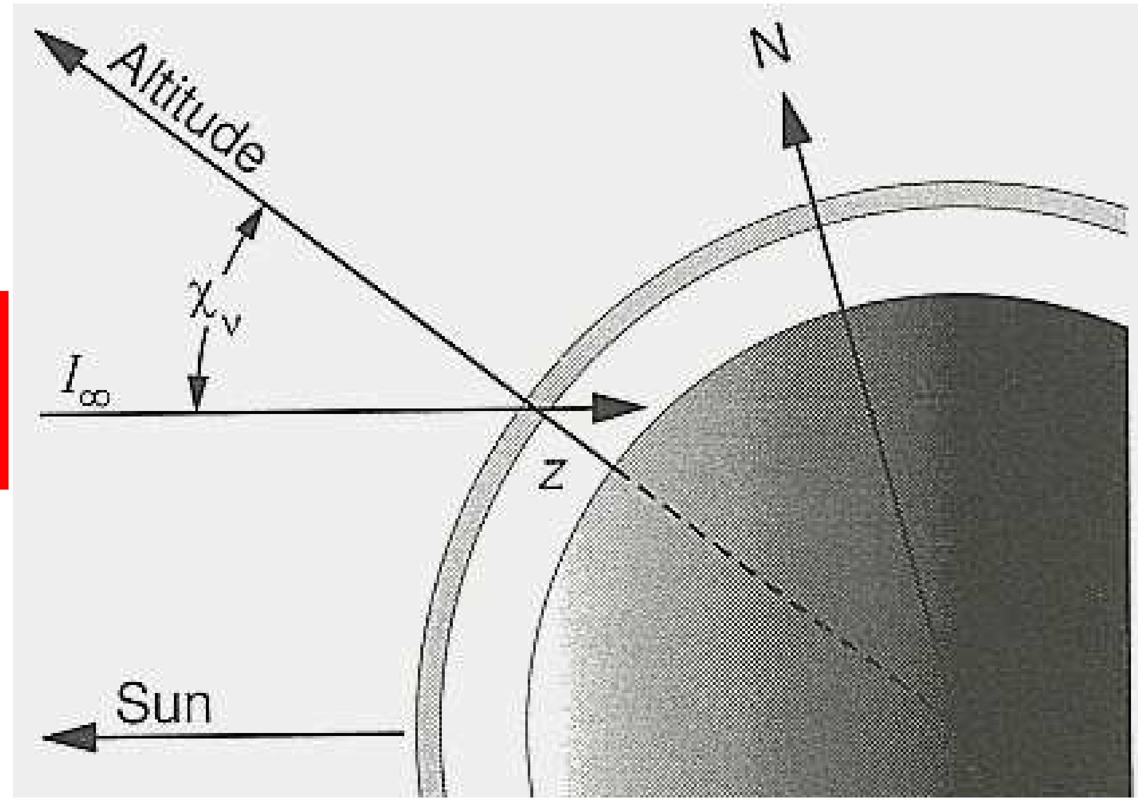
The ionosphere

Neutral atmosphere stratified according to barometric law:

$$n_n(z) = n_0 \exp(-z/H)$$

$H = k_B T_n / m_n g$

= scale height



Solar ultraviolet radiation impinges at an angle χ, the radiation is than absorbed in the upper atmosphere where it creates ionization (also through electron precipitation).

g is the gravitational acceleration at $z = 0$

n_0 is the plasma or the neutral density at $z = 0$

I_∞ is the flux on top of the layer.

Diminuation of the solar UV radiation

Radiation transfer -> the solar radiation is diminished with altitude along the ray path in the atmosphere:

$$dI = \sigma_\nu n_n \frac{dz}{\cos\chi_\nu} I$$

[redacted] is the radiation absorption-cross.section for a photon of frequency [redacted] Solving for the intensity ->

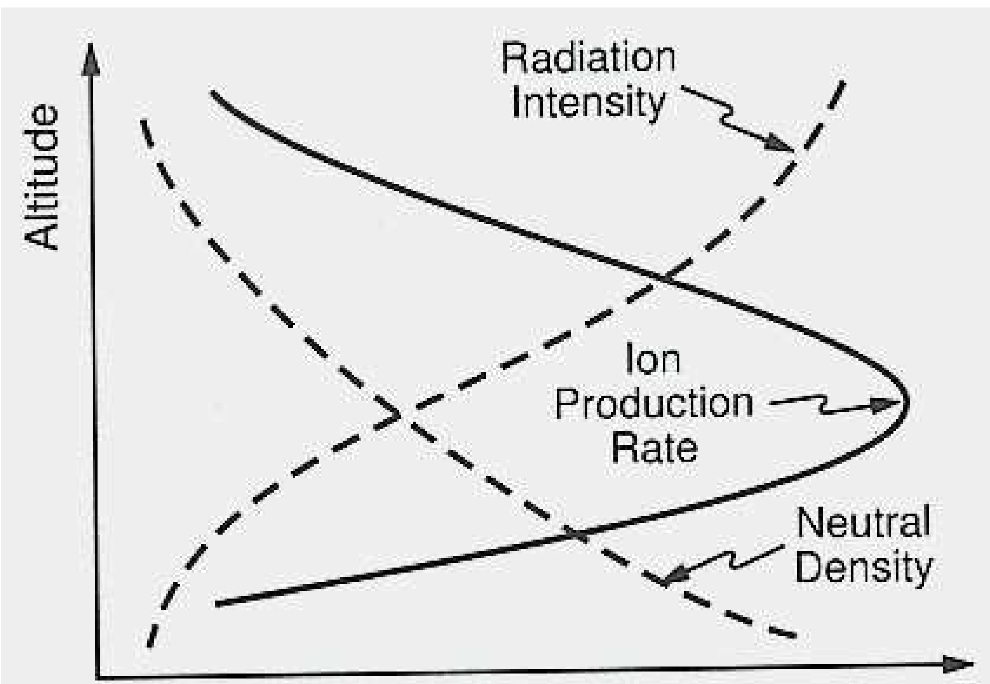
$$I(z) = I_\infty \exp\left[-\frac{\sigma_\nu n_0 H}{\cos\chi_\nu}\exp(-z/H)\right]$$

This reveals an exponential decrease of the intensity of the solar ultraviolett radiation with height, the dashed line in the next figure.

Formation of the Chapman layer

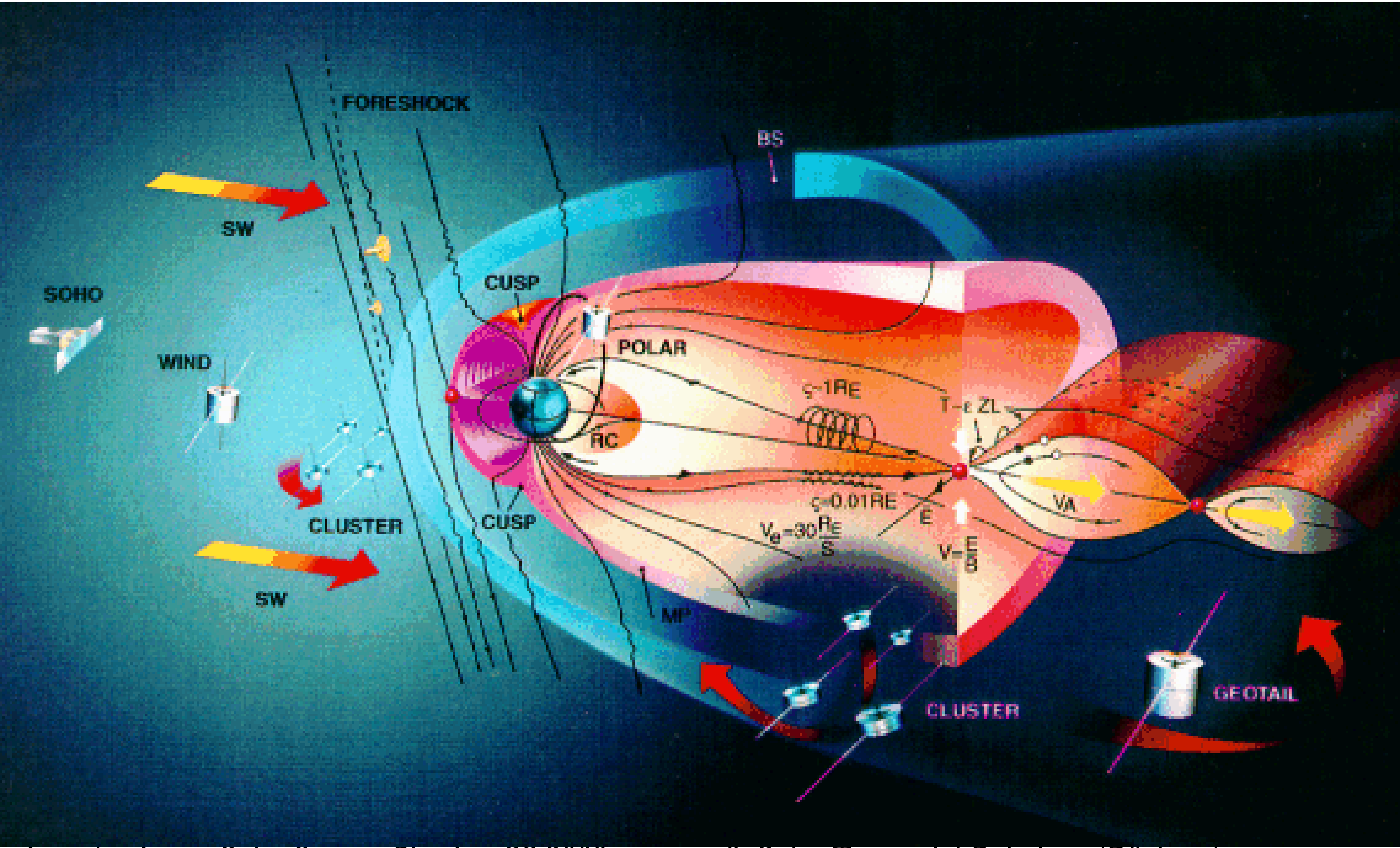
$q_\nu(z)$: electron-ion pairs produced by UV ionization proportional to the ionization efficiency, κ_ν, and absorbed radiation: $q_\nu(z) = \kappa_\nu \sigma_\nu n_n I(z)$ -> Chapman layer:

$$q_\nu(z) = \kappa_\nu \sigma_\nu n_0 I_\infty \exp\left[-\frac{z}{H} - \frac{\sigma_\nu n_0 H}{\cos\chi_\nu}\exp(-z/H)\right]$$

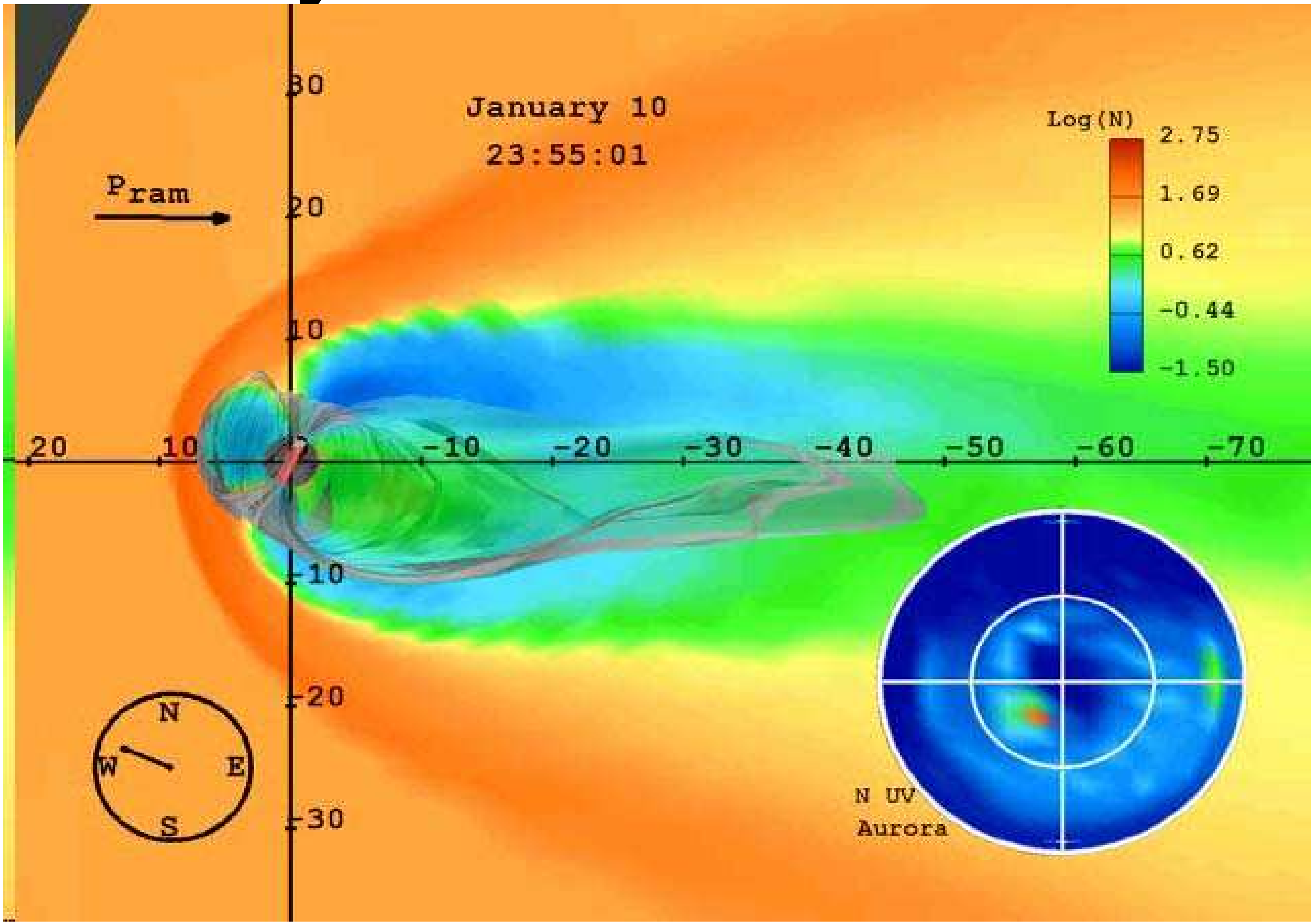


The location of the ionization maximum varies with time, season etc. Due to its importance for radio propagation it was called the F-layer, later D and E layers were discovered

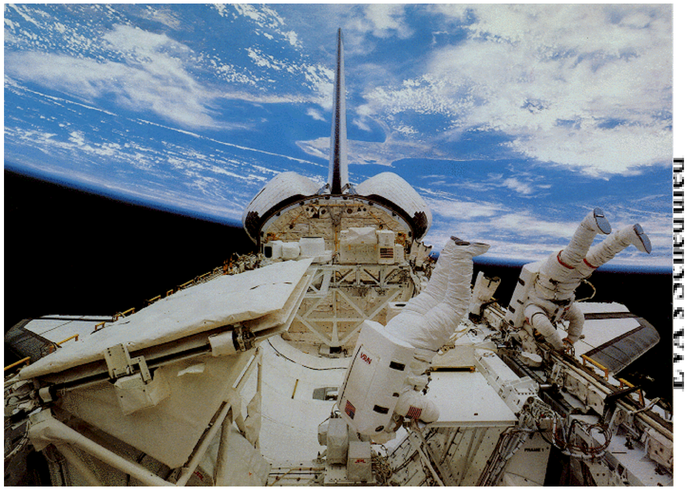
Local information: fleet of spacecraft

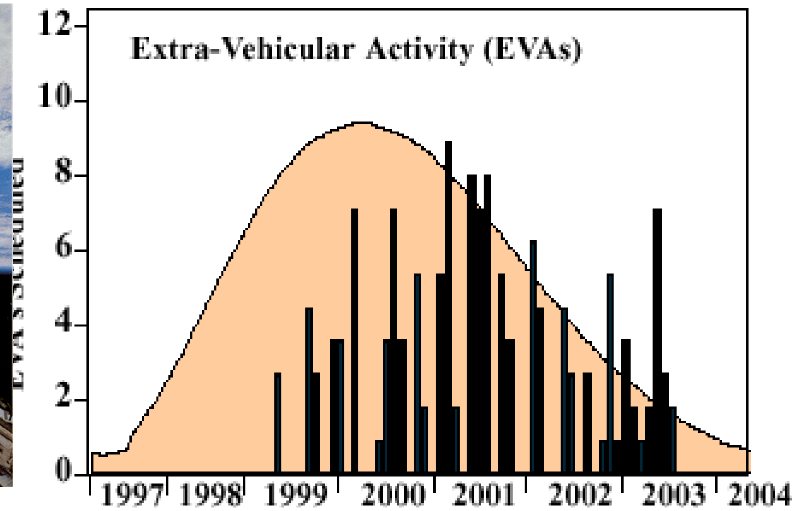


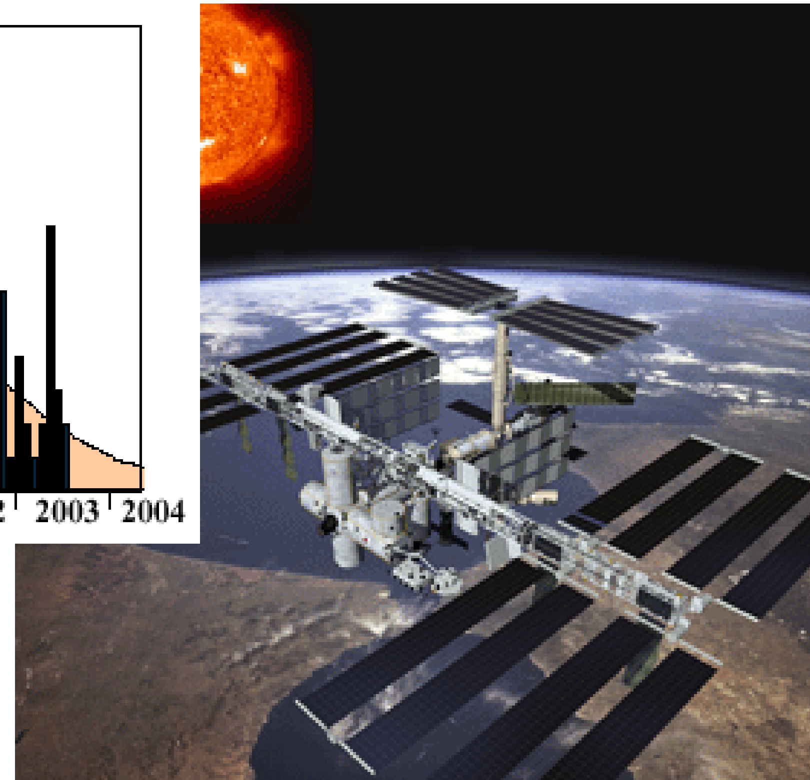
Global dynamics: Numerical models

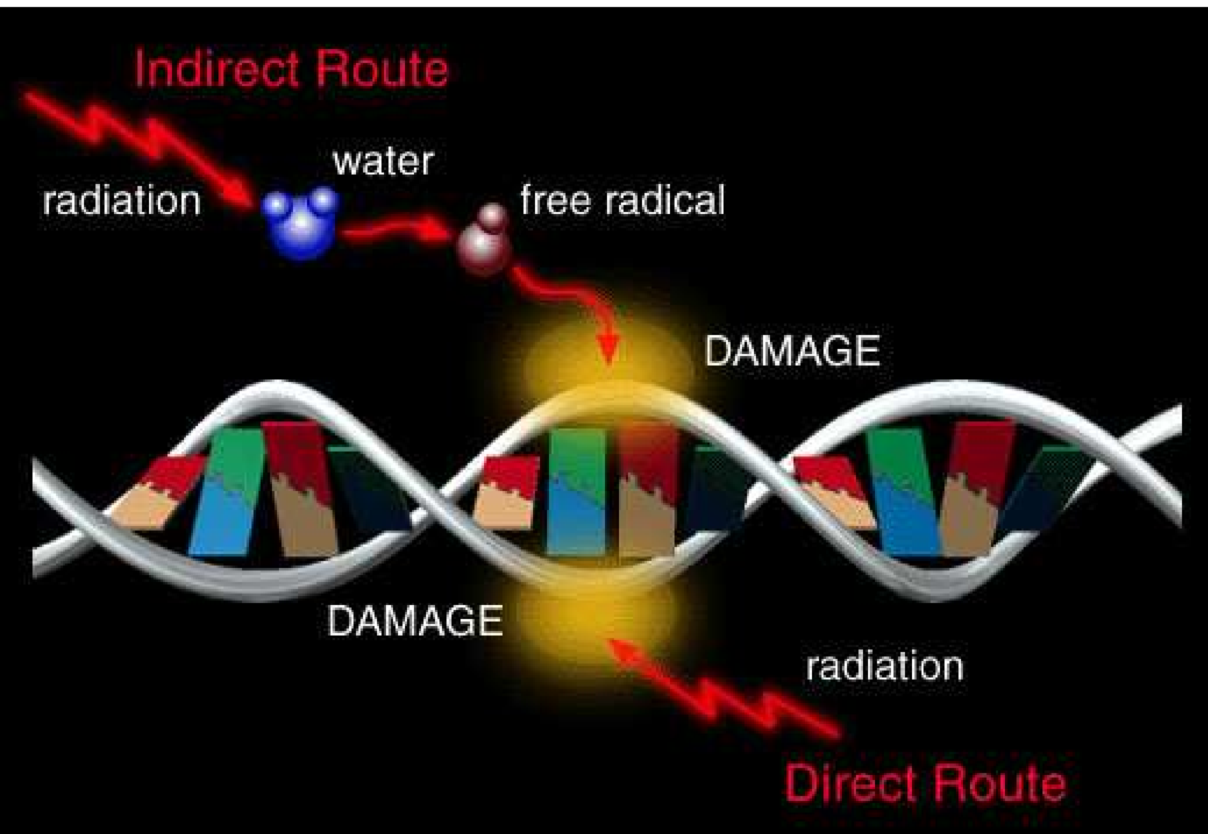


Consequences: 1. Men in Space

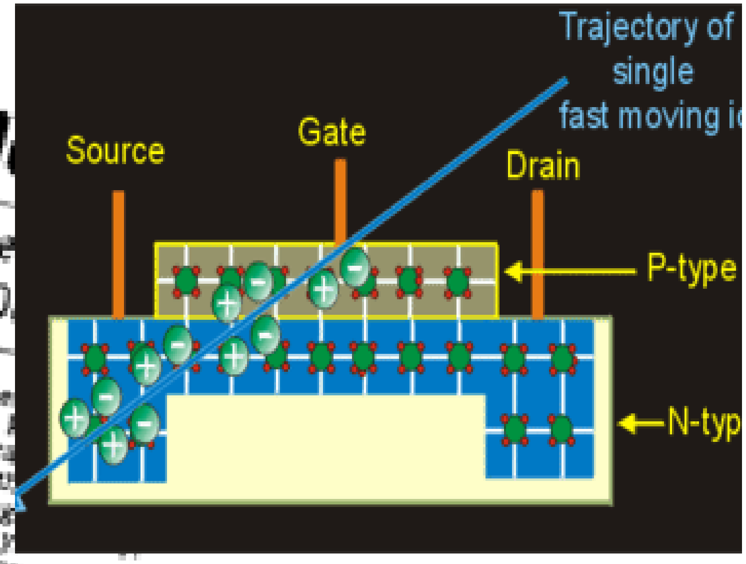


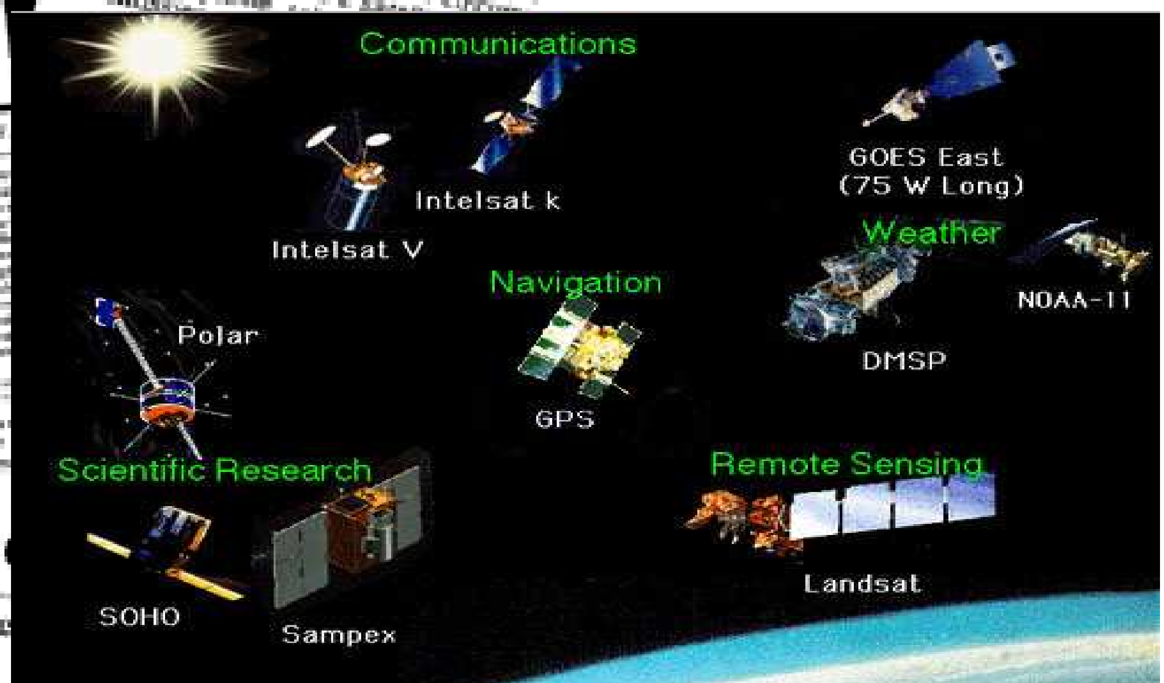






2. Danger for satellites





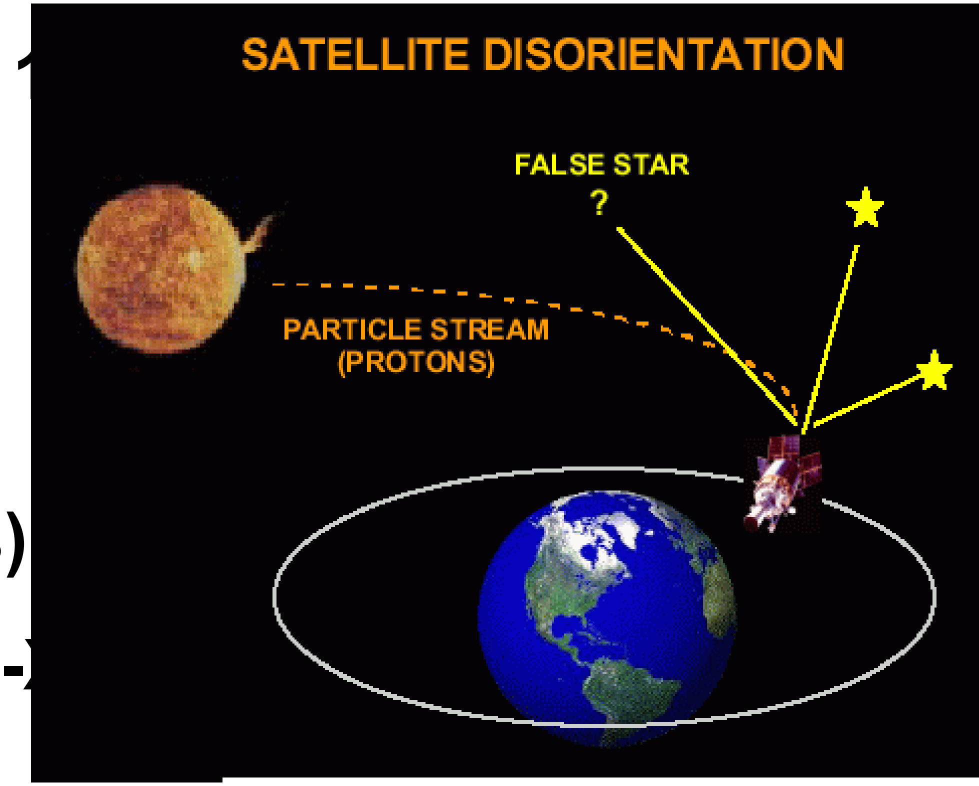
Damage / loss of satellites

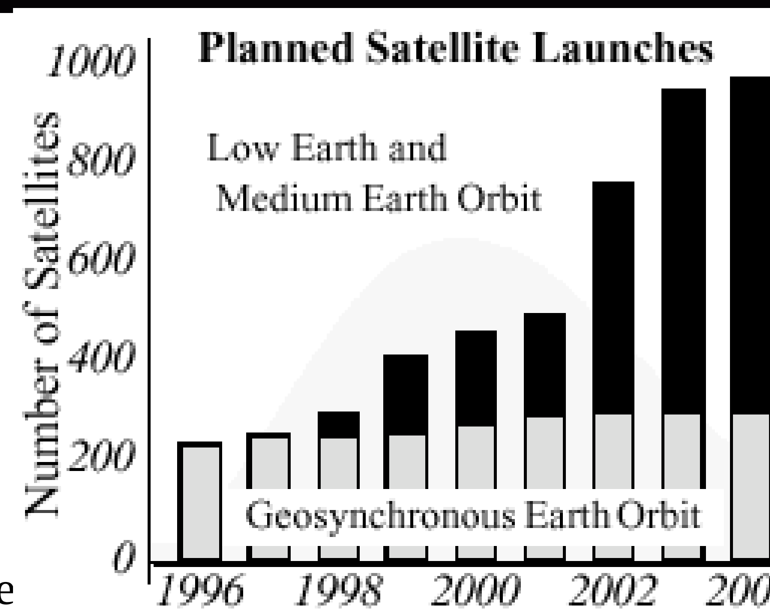
- Damaged microschemes (Anik 1
- Disorientation of satellites
- contact lost (ESR-1, PRARE, Equator-S)
- Anomalous charges (Electrons)

  (Marecs, ECS, Meteosat, TELE-X
- Degradation of solar panels

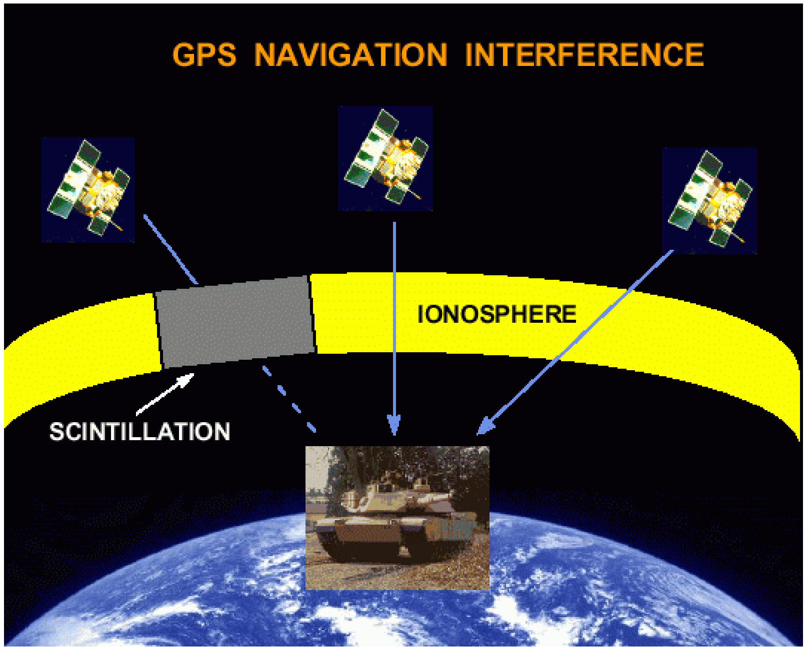
  (Tempo, PanAm, ECS)

- Total losses of satellites by solar storms (Telestar 401, Galaxy IV)
- Last four years: 5 Billion EUR lost

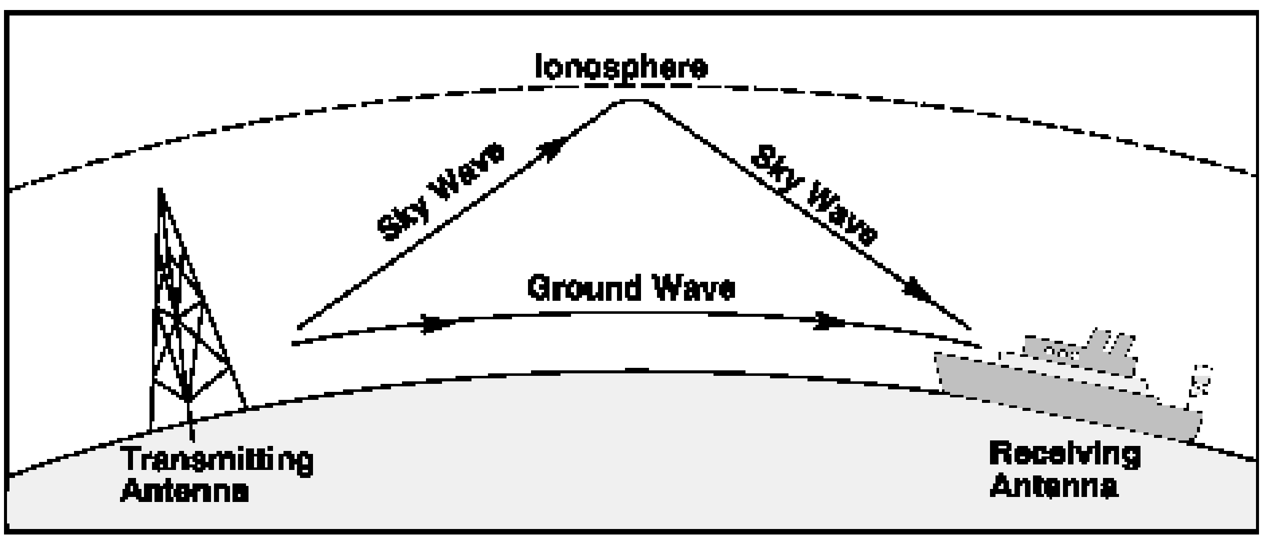


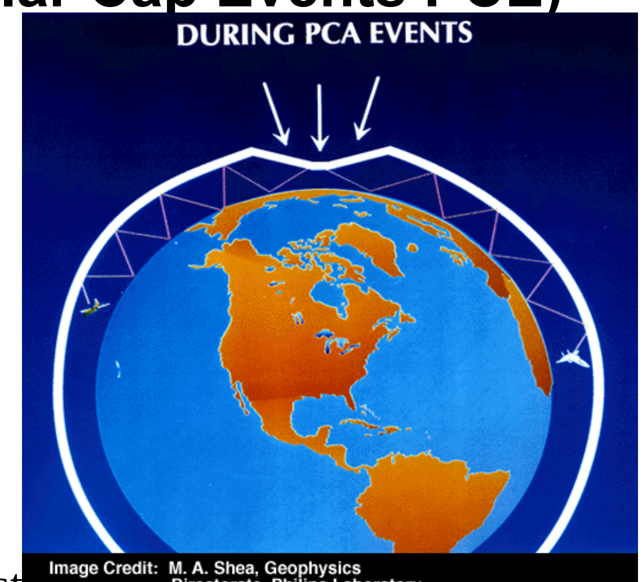


Influence on navigation systems (GPS, GLONAS, GALILEO)

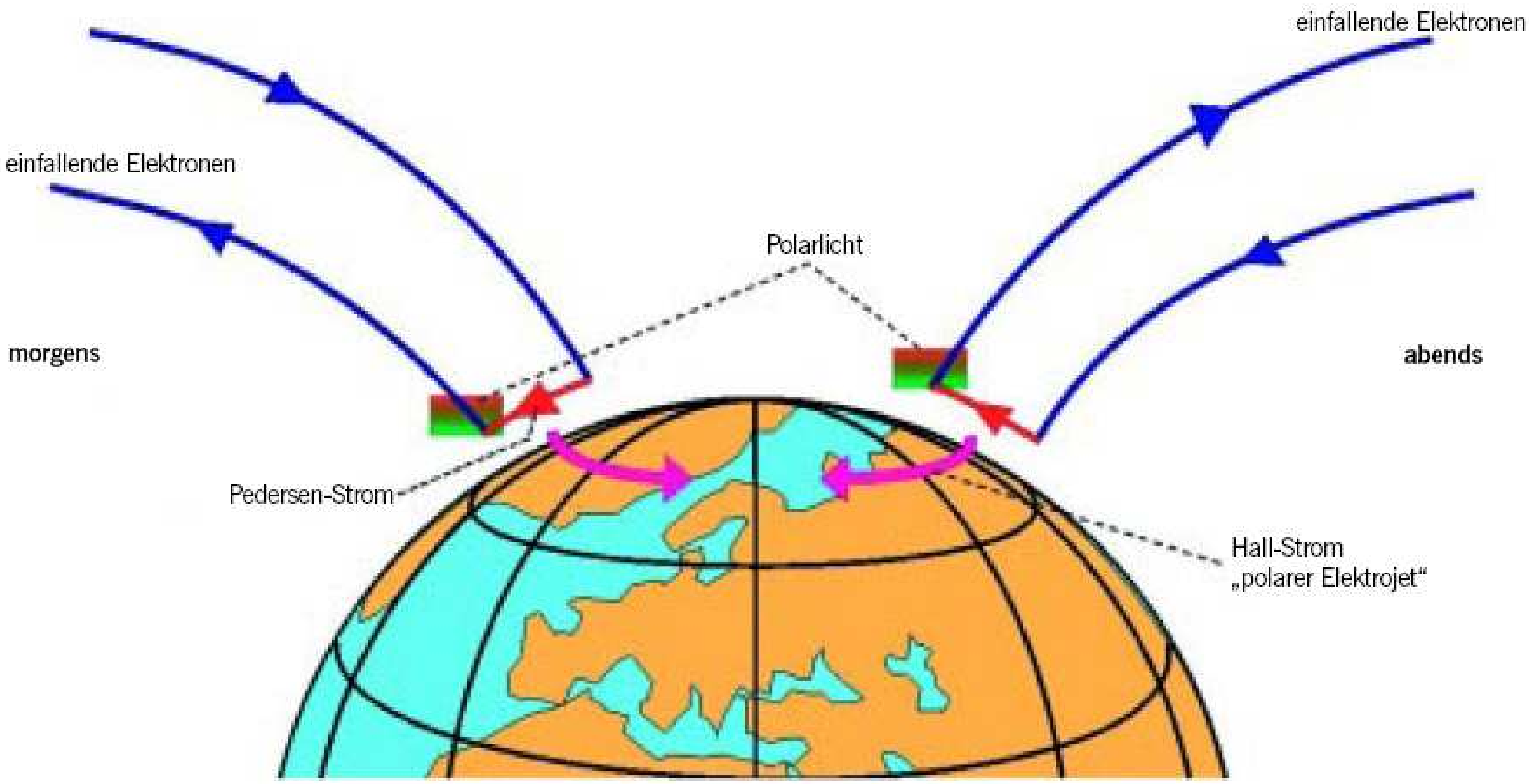


- Ionosphere between satellites and ground users becomes turbulent and irregular, Signals "scintillate" or are lost completely
- Changing total electron contents along the propagation path: errors in the GPS signal hundredes of meters
- Distortion of radio wave propagation (e.g. during Polar Cap Events PCE)





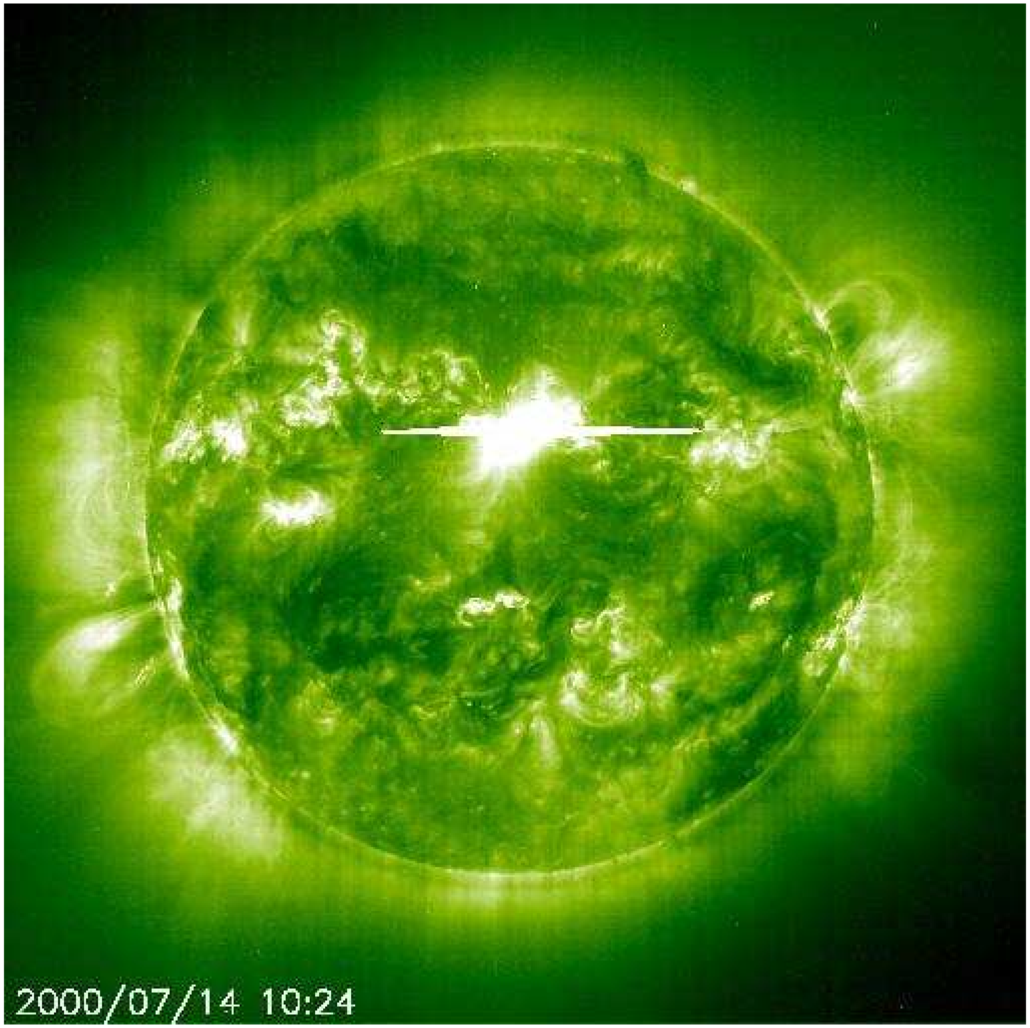
Consequences of currents

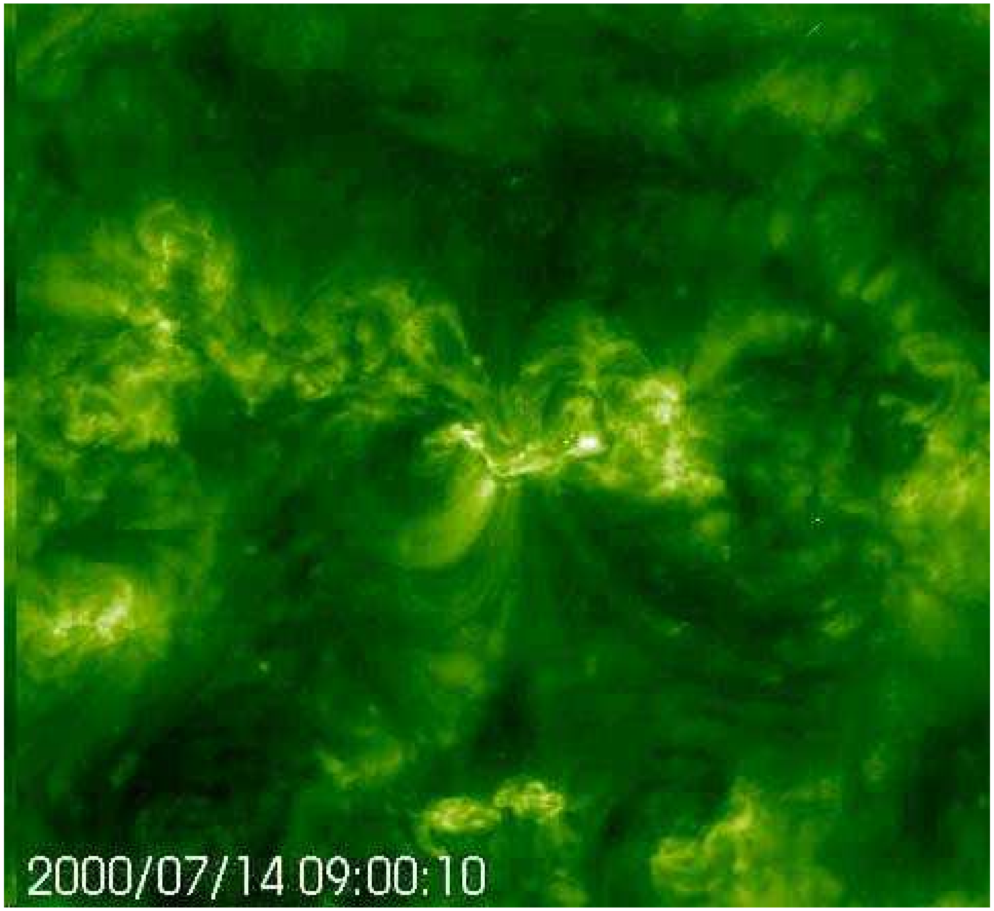


Field aligned (Birkeland-) currents close via Pedersen currents, which produce Hall currents.
Electrons > 1 keV cause aurora („polar lights“).

Aurorae

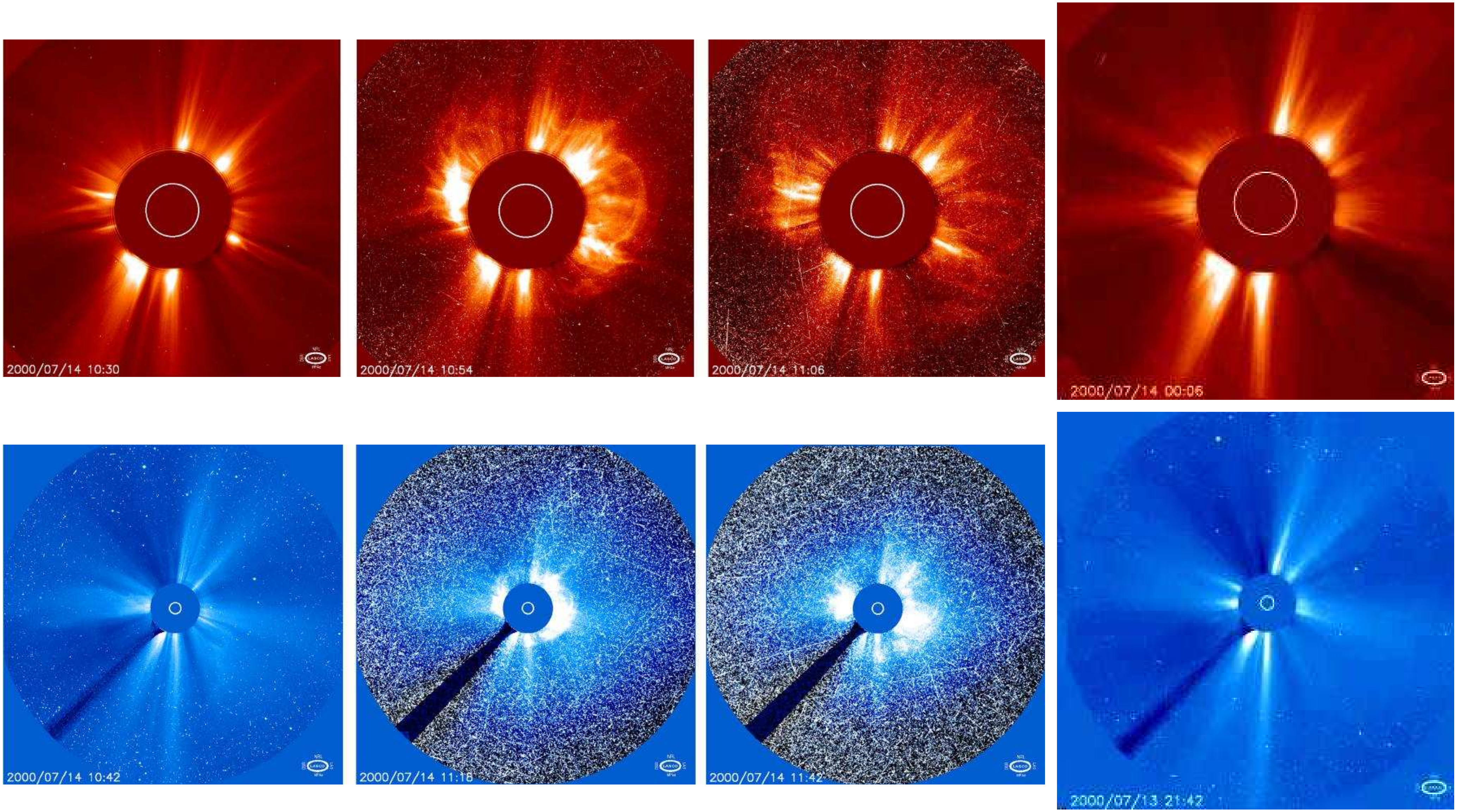
Example: Bastille day 14.7.2000



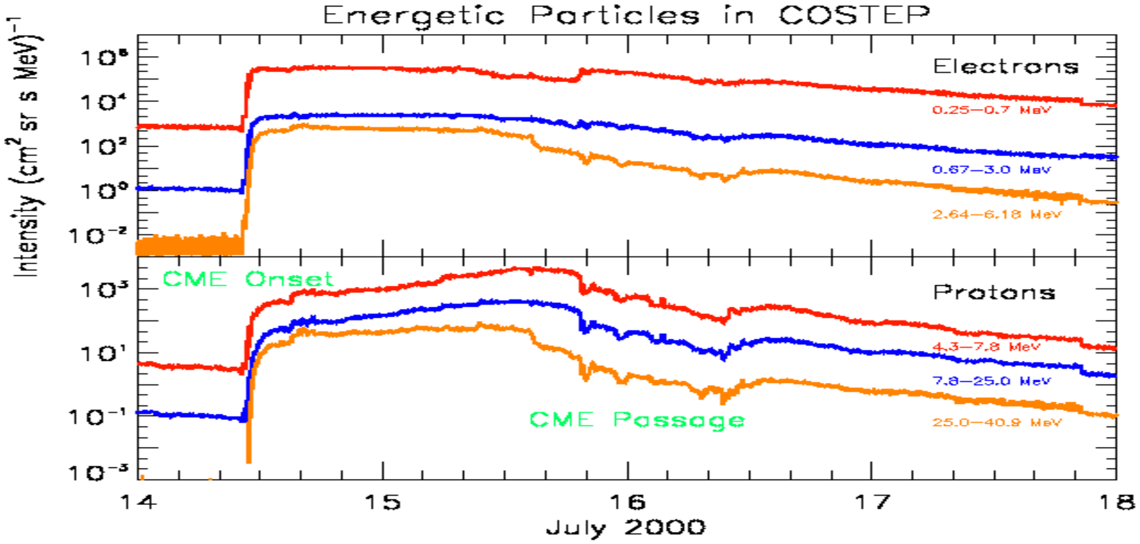


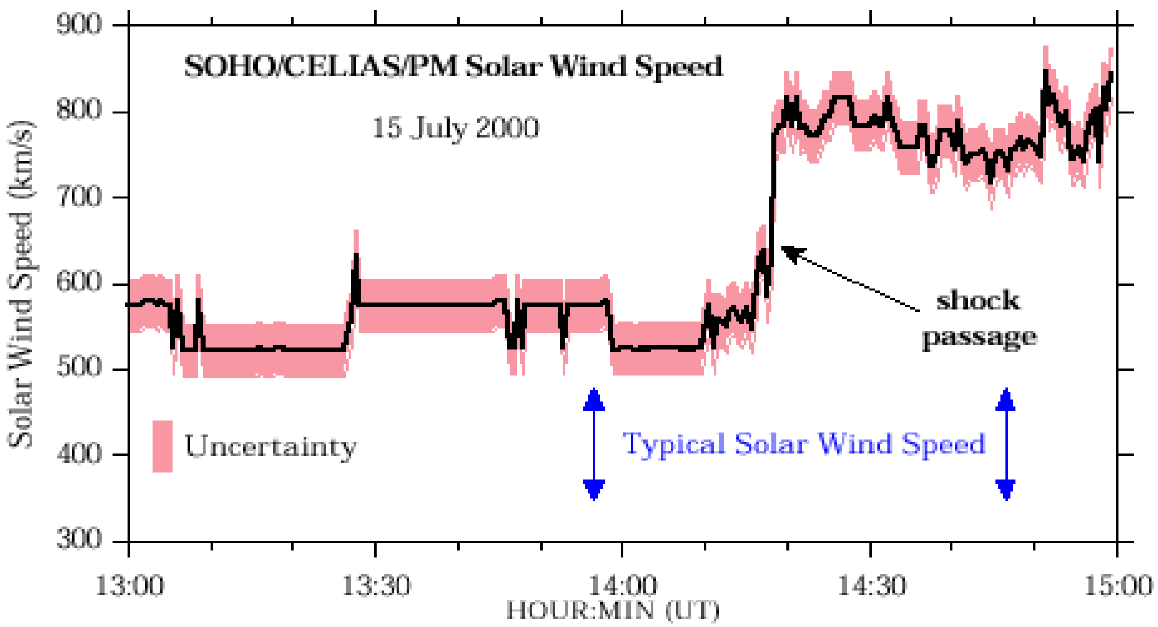
Flare observation by SOHO EIT: movie

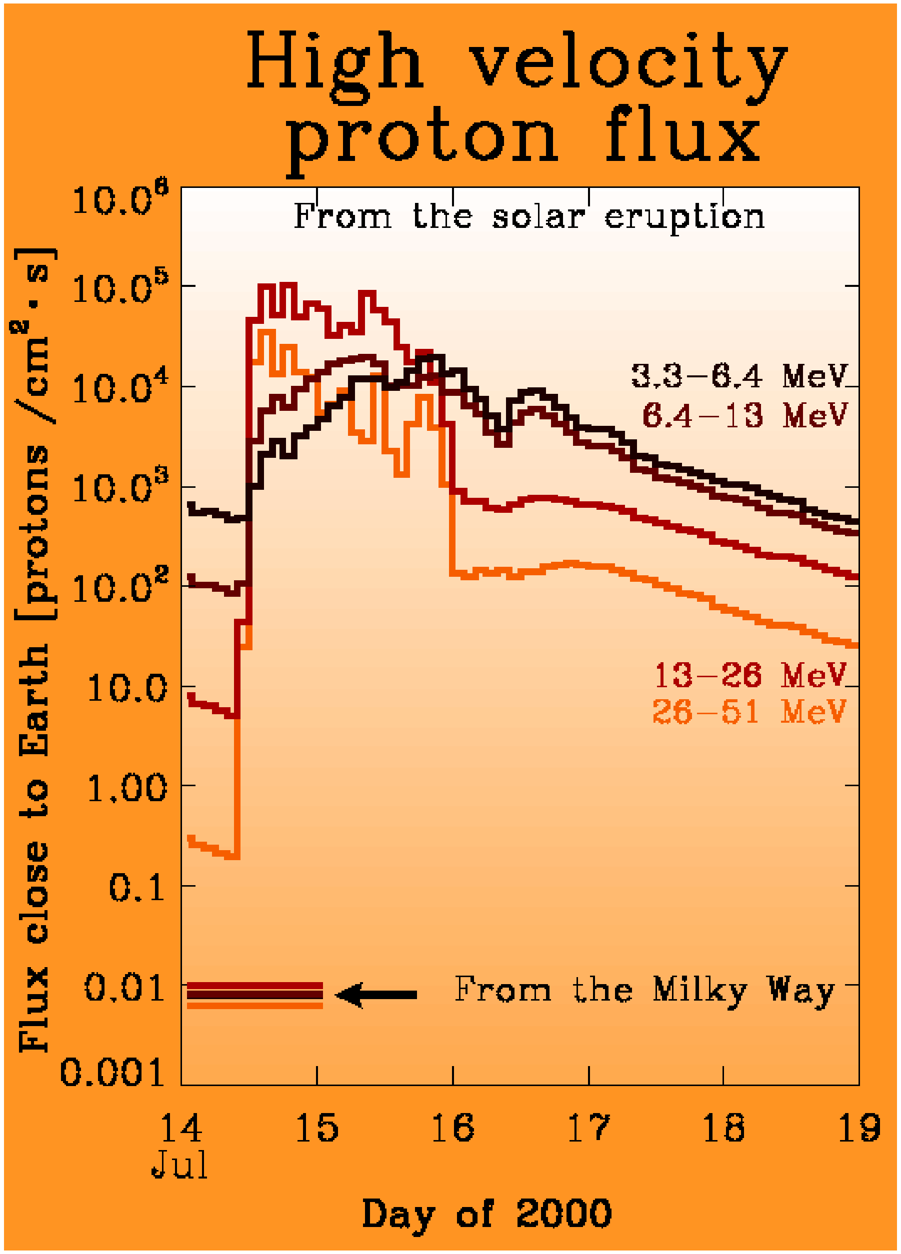
Bastille day 14.7.00: LASCO



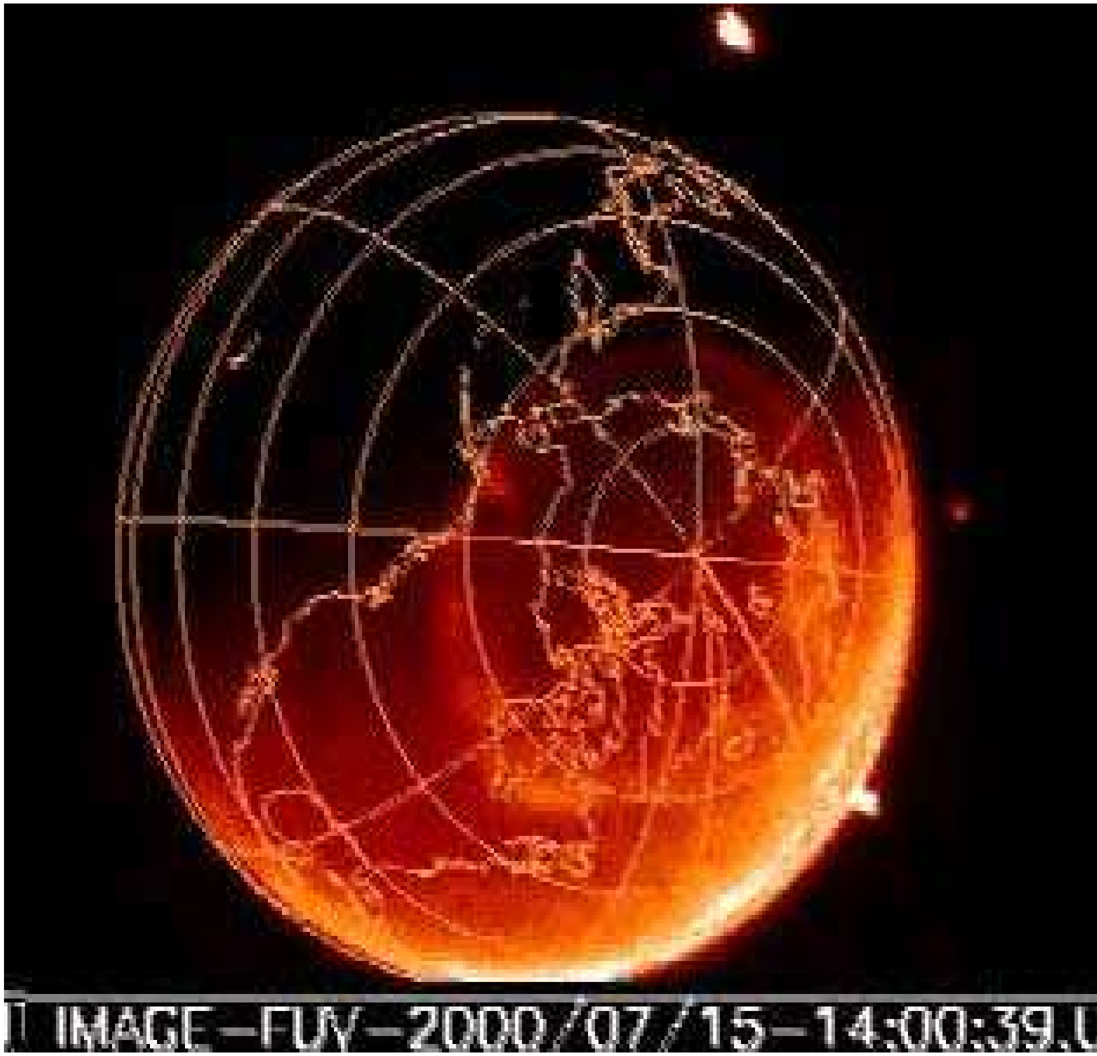
Bastille day 14.7.00: particles

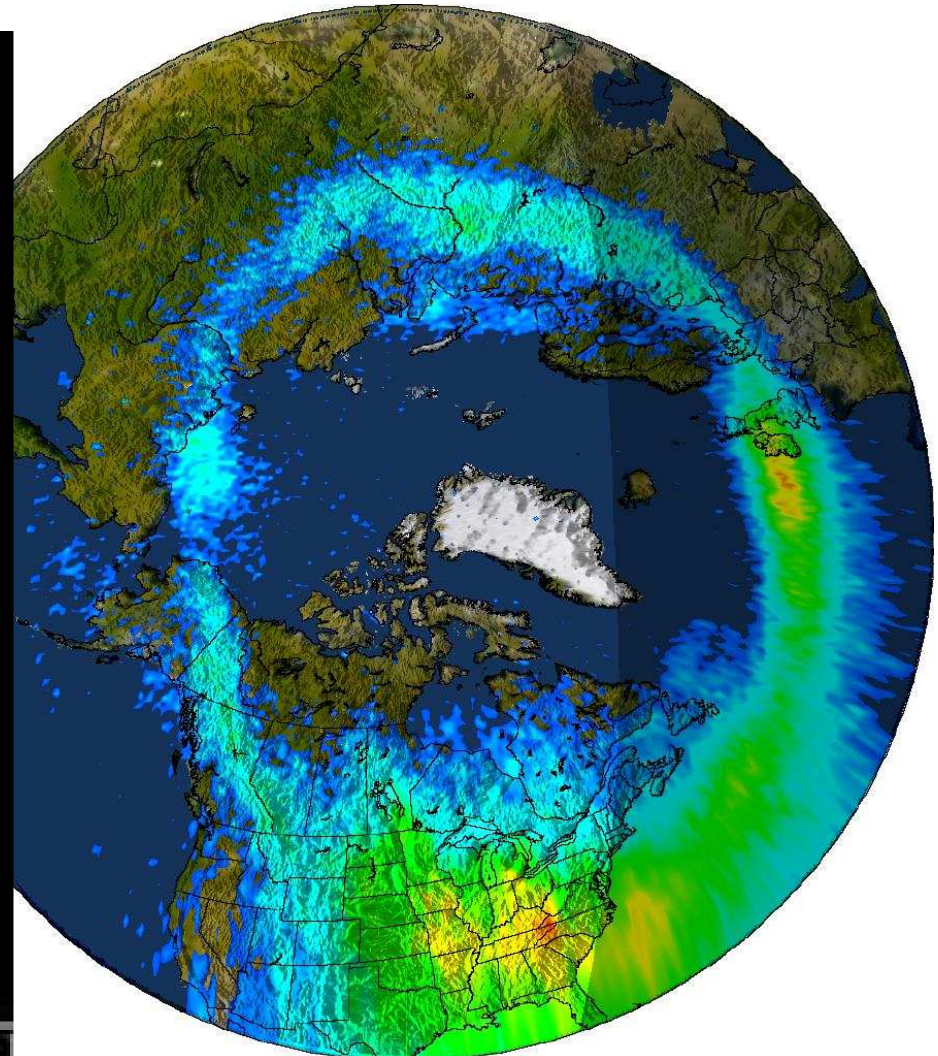




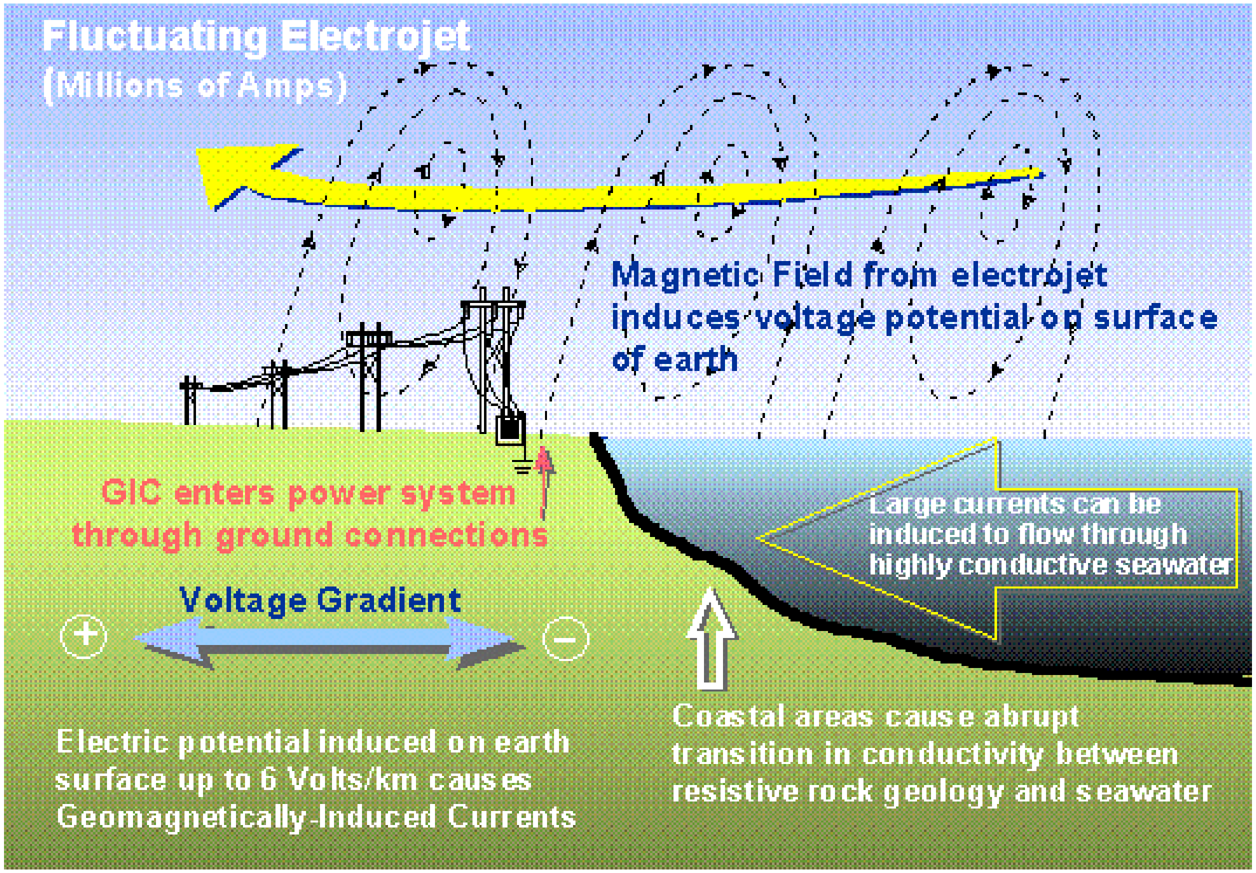


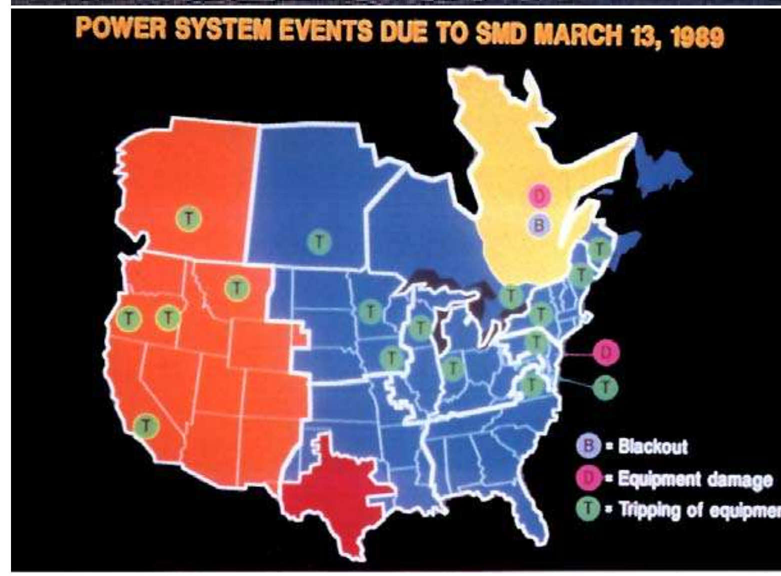
Bastille day 14.7.00 aurorae





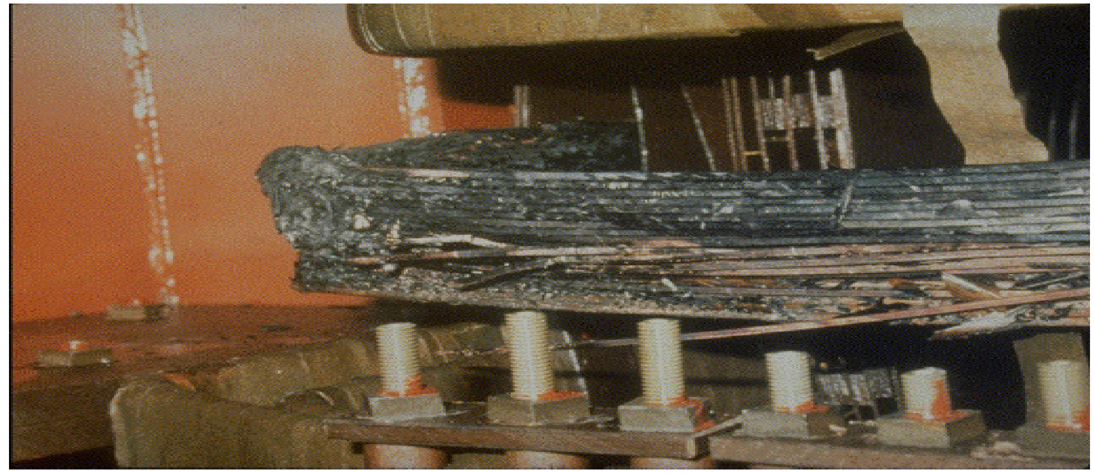
Geomagnetic storms -> inductions

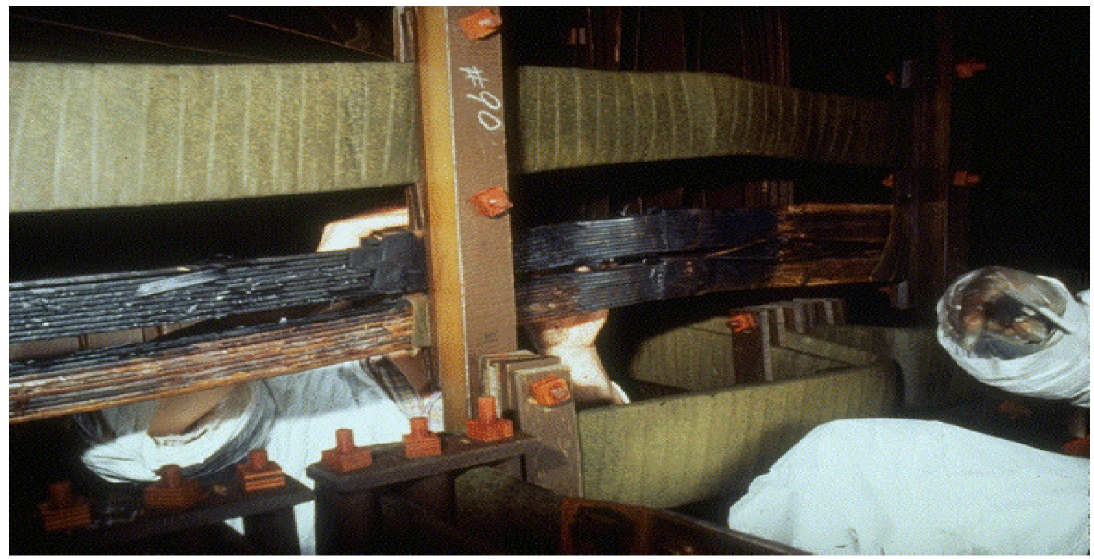




- GICs = Geomagnetically Induced Currents
- Inductions into long pipelines
- Railway systems
- Communication lines

Burned Transformers





March 1989: **Delaware power station transformer damage**

Sweden: Six 130 kV power lines disrupted

April 1994: **Chicago station: Five Transformers lost**

Summary: Solar influence

Flares	CMEs und Flares	CMEs, coronal holes
Electromagnetic radiation (X-rays, EUV, Radiobursts)	Energetic protons	Plasma and particles
Arrival: Immidiate	Arrival: 15 minutes - hours	Arrival: 2-4 days
Duration: 1-2 hours	Duration: days	Duration: days
Consequences:	Consequences:	Consequences:
Satellite communication disturbed, Radarinterferences Short waves fade away	Disorientation of satellites, Sensor errors, Destruction of of spacecraft Radiation danger for airplanes at heights	Geomagnetic storms, Satellite charges, Navigation Errors Radar-interferences Wave propagation anomalies Power outages, Staining of pipelines

Summary: Space Weather