DYNAMOS in SUN EARTH SYSTEM

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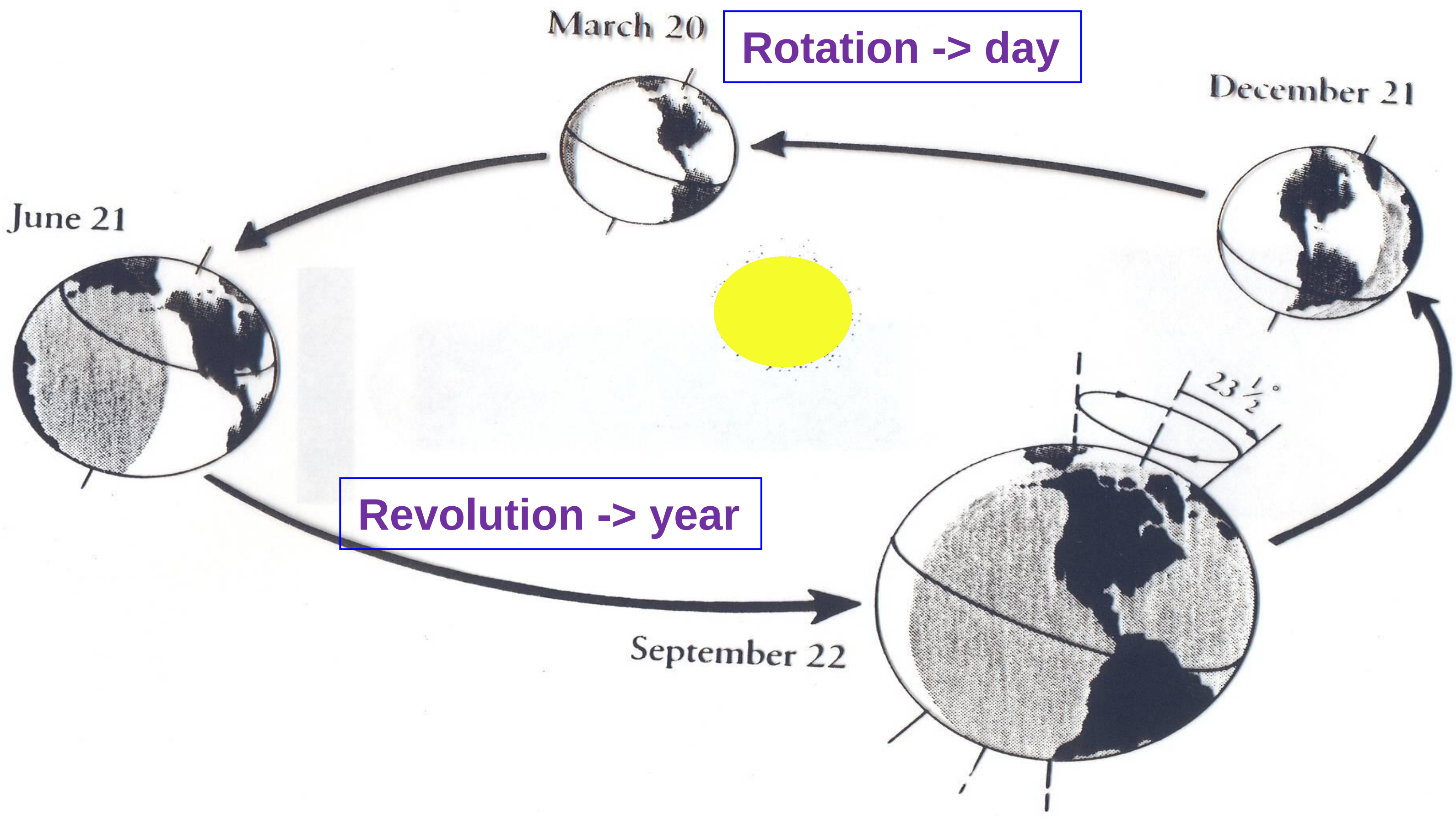
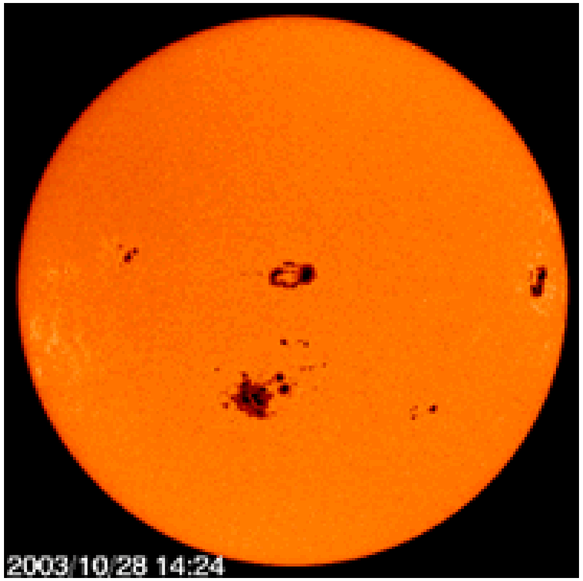
Summary

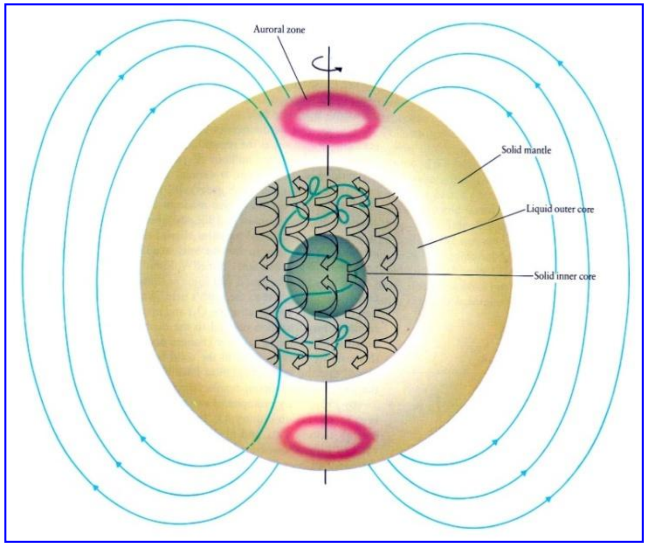
- Space weather
  - Definitions
- Sun Earth Links through dynamo processes
  - The main dynamo => Research project
- Electric current systems associated to dynamo

Motion of planets
Gravity force – Kepler 's laws





Sun and Earth magnetized bodies in motion



Dynamo Processes in the Sun Earth System

↓

systemic analysis

Space weather includes many disciplines of the Physics

Solar physics

Studies on solar wind

Magnetospheric physics

Ionospheric studies

Atmospheric physics

Geomagnetism

Magnetotelluric studies Geology

GNSS

Etc…

Summary

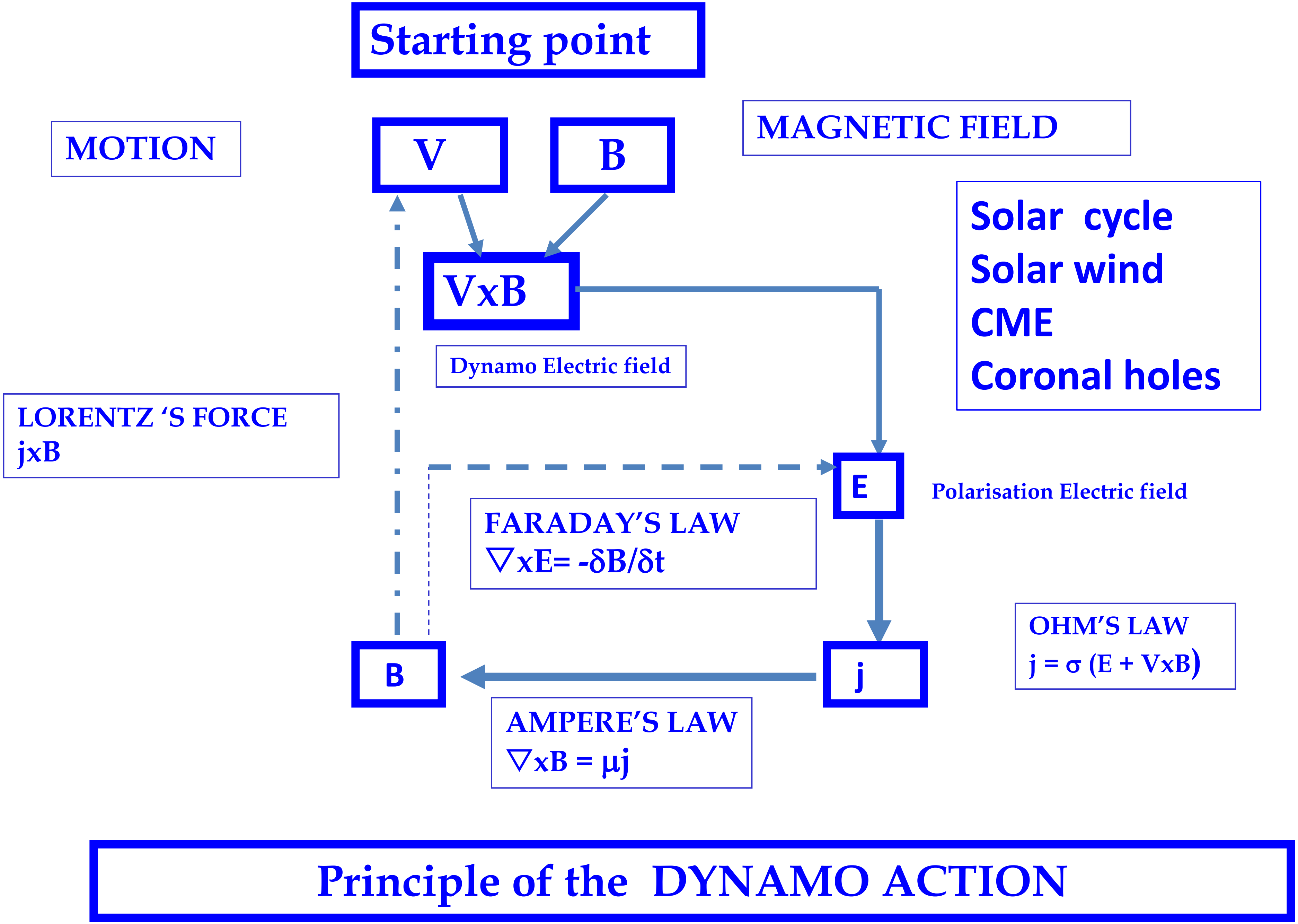
Space weather

Definitions

Sun Earth Links through dynamo processes

The main dynamo => Space weather project

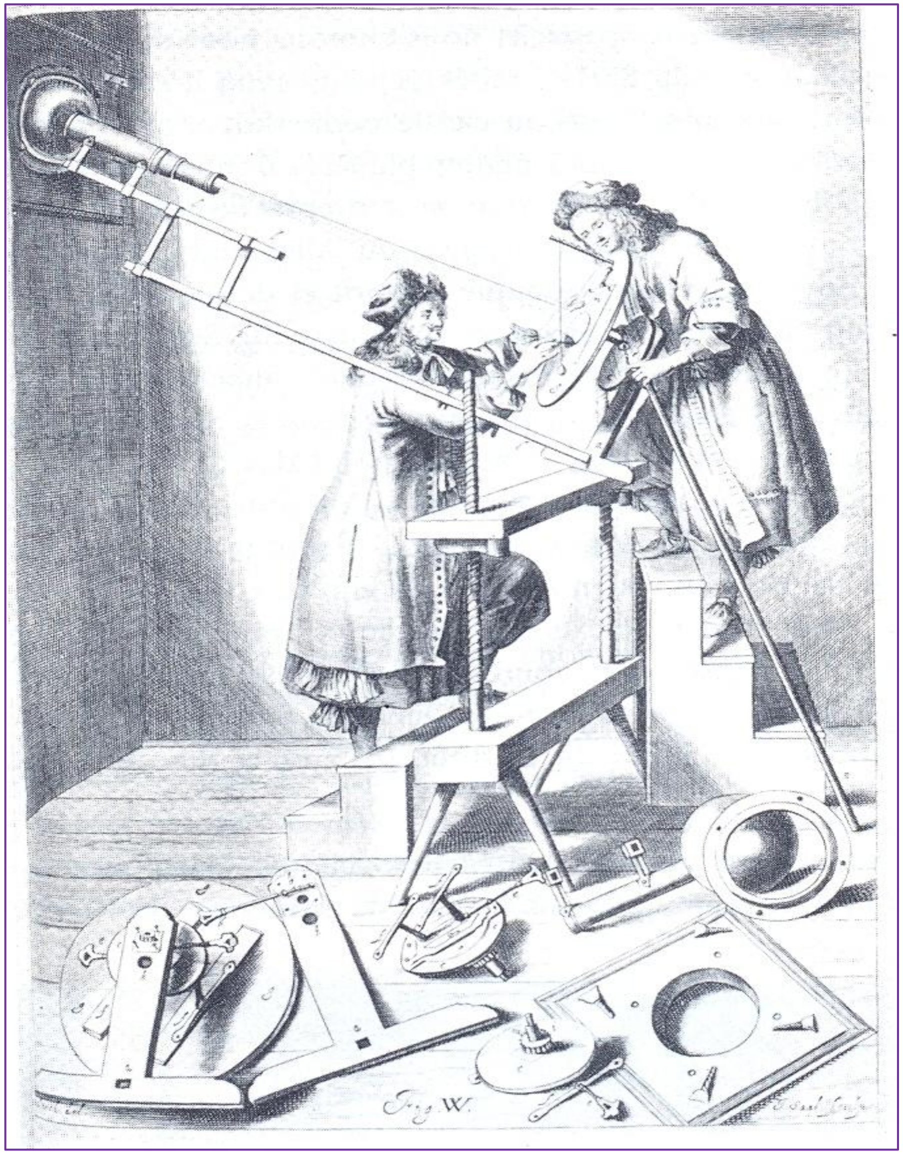
Electric current systems associated to dynamo



Starting point
MOTION
V
B
MAGNETIC FIELD
Solar cycle
Solar wind
CME
Coronal holes
VxB
Dynamo Electric field
LORENTZ 'S FORCE
jxB
E
Polarisation Electric field
FARADAY'S LAW
∇xE= -δB/δt
OHM'S LAW
j = σ (E + VxB)
B
j
AMPERE'S LAW
∇xB = μj
Principle of the DYNAMO ACTION

SOLAR DYNAMO

Observation of the Sun : Sunspots

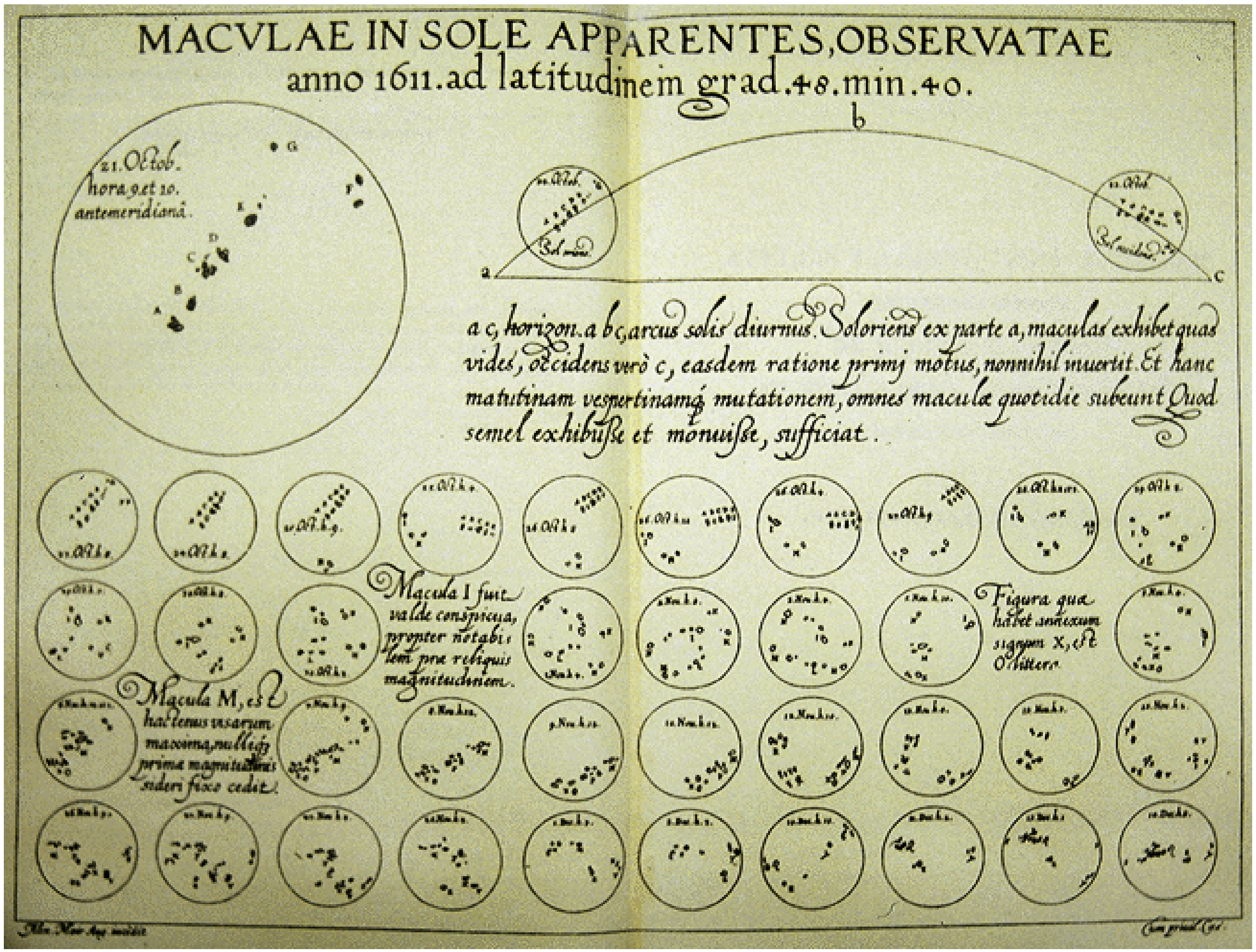


Hévélius
1642- 1644

They used a telescope through an inversed wooden globe inserted in a circular width made in a shutter. They observed the sunspot by projection of its shadow on a cardboard

(Machinae Celestis, 1673
Legrand et al., 1991)

Observation of the Sun : sunspots



Galileo
Spring 1611

Christophe Scheiner
October 1611

Johannes Fabricius
First publication
Automn 1611

Observation of sunspots

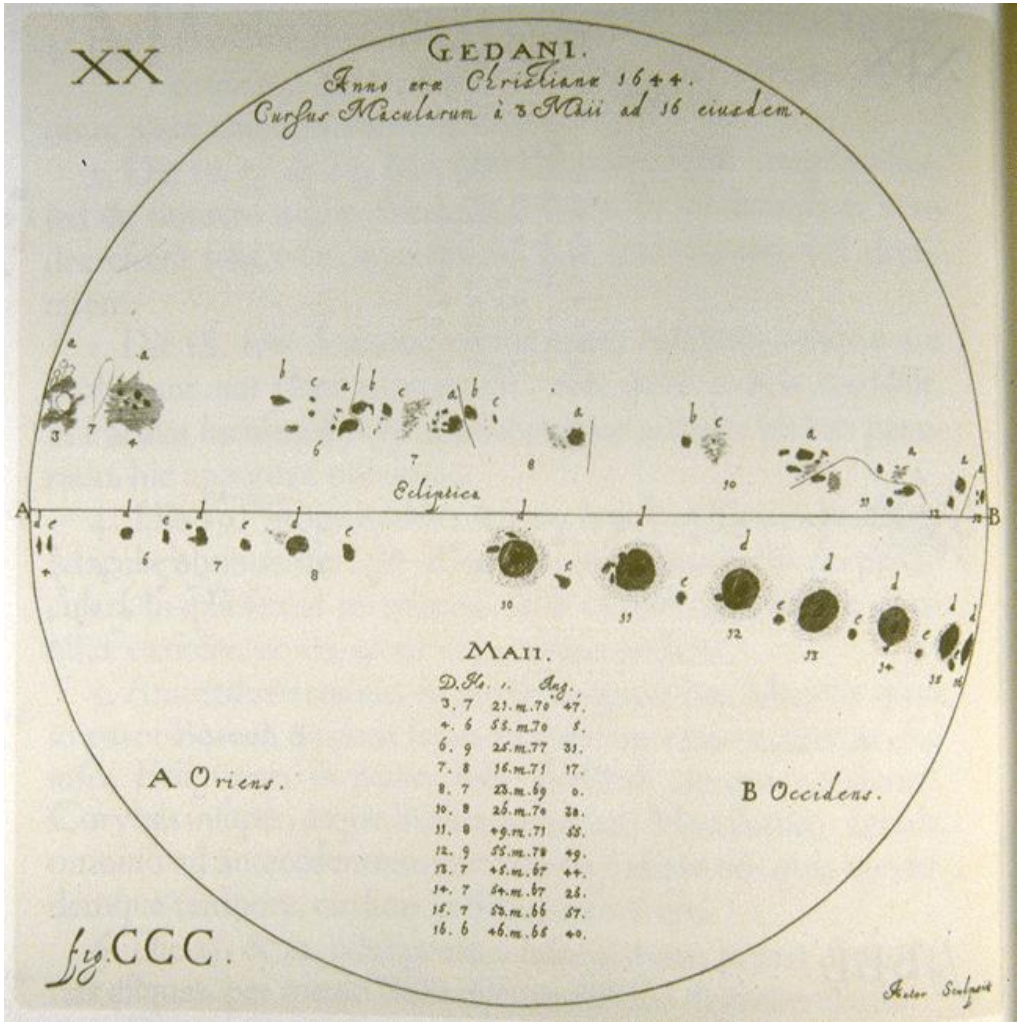
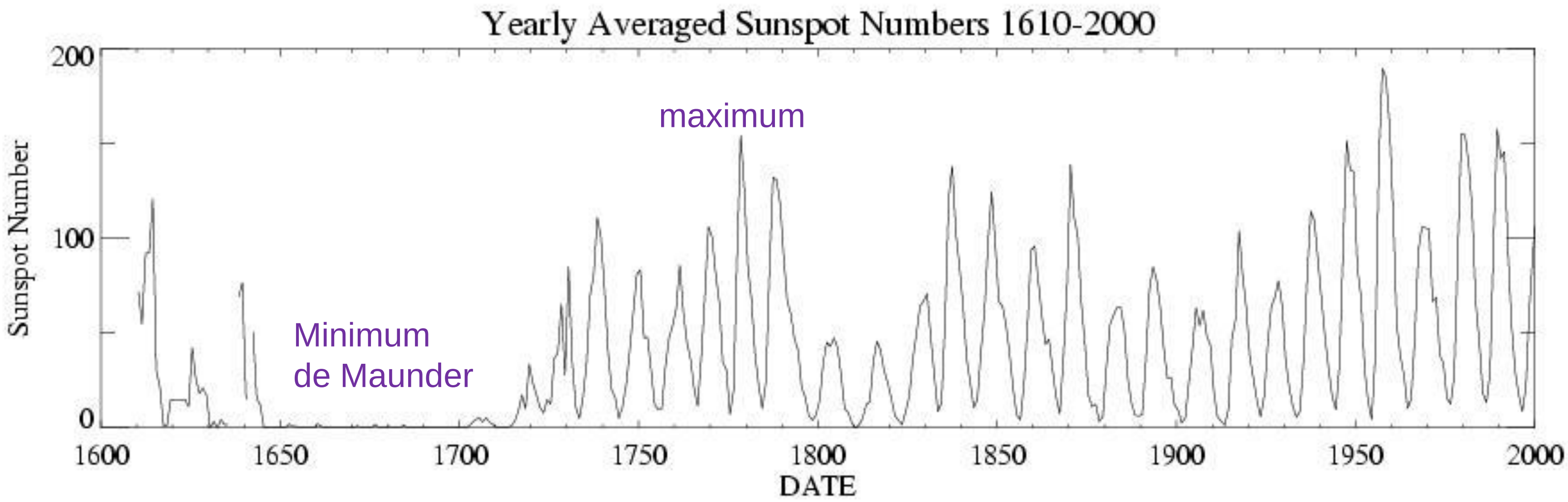


Figure of Father Scheiner
Motion of the sunspots

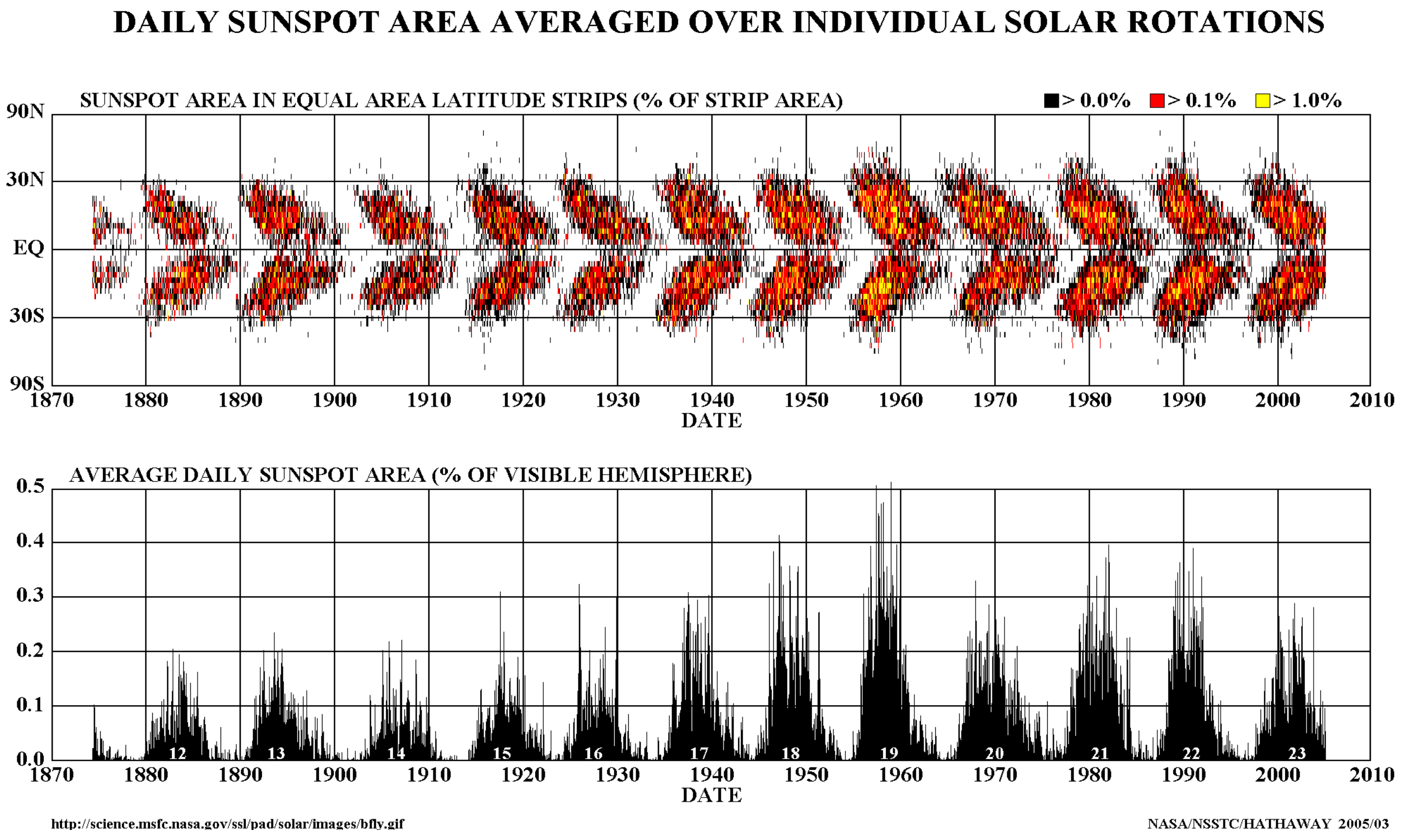
Scheiner : Priest Jesuit mathematician working at the university of Ingolstadt (near Augsburg)

Solar Cycle of 11 years : Heinrich Schwabe 1859

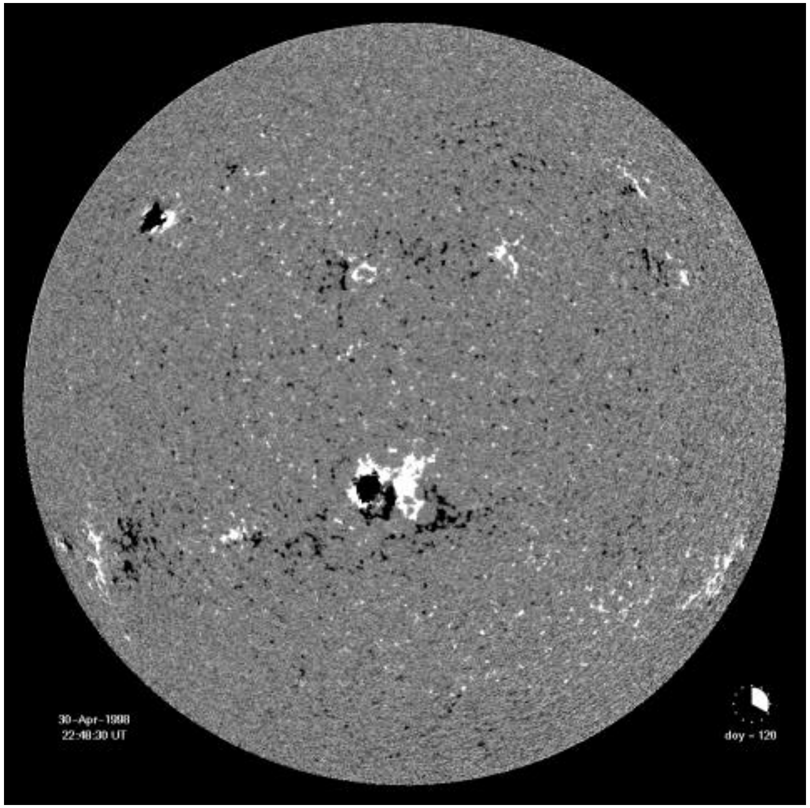


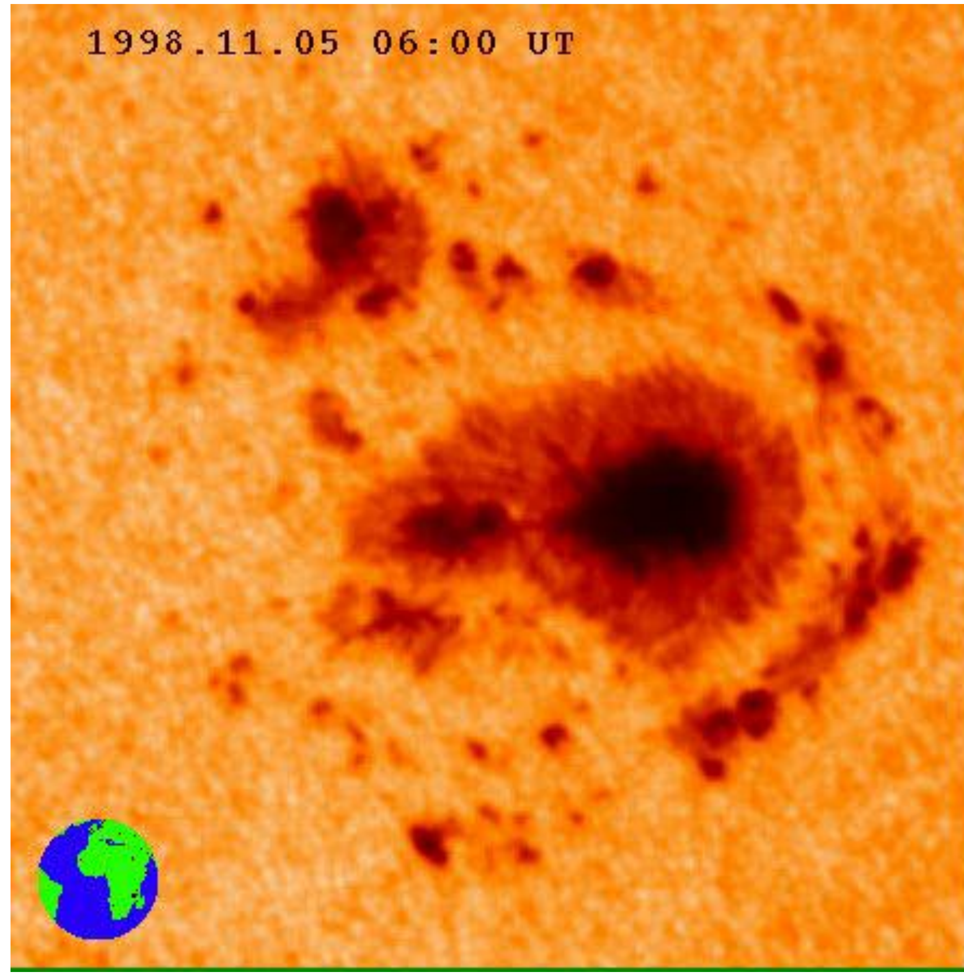
Annual variation

Observation of the Sun : sunspots



Magnetogram of the sun

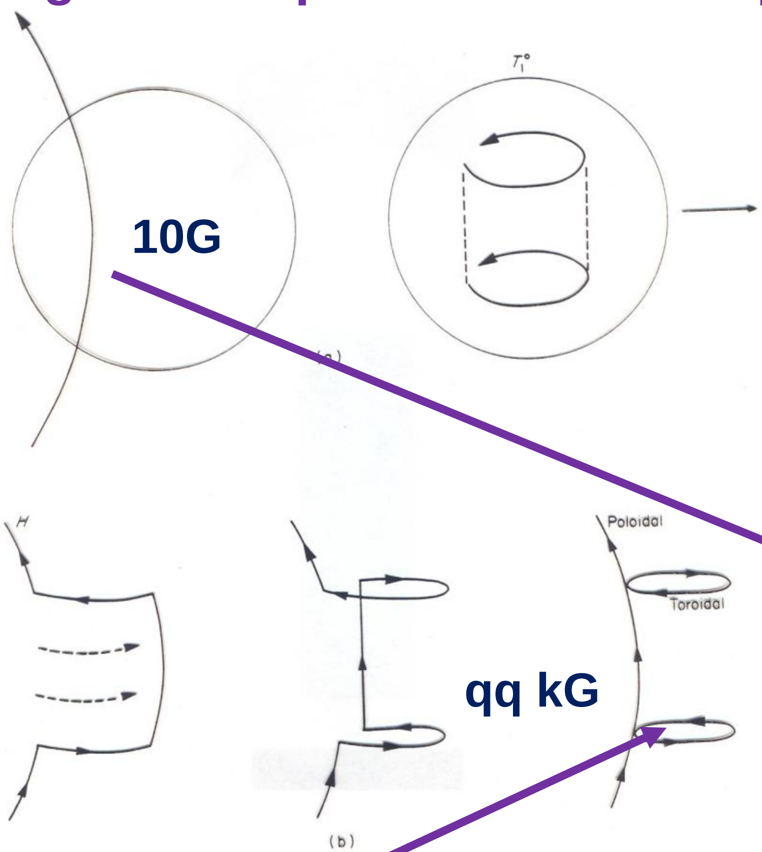


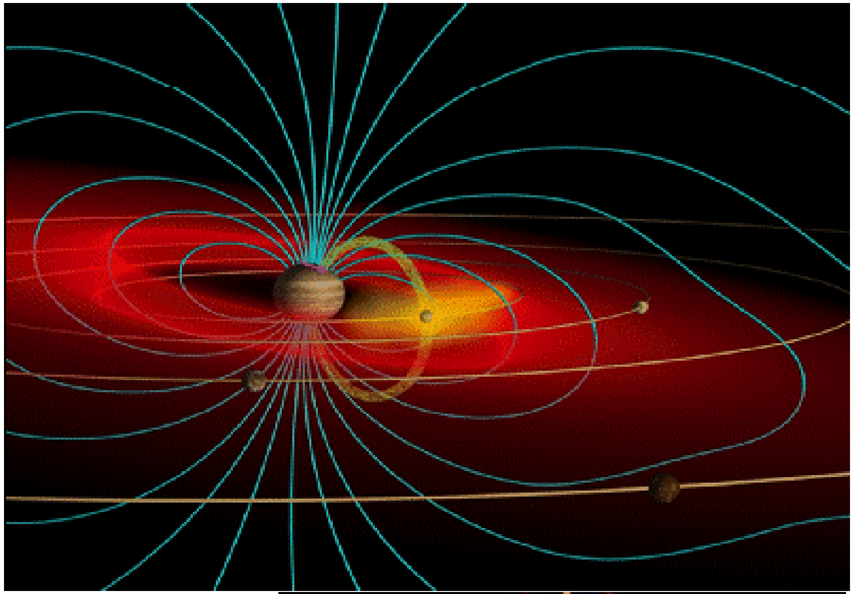


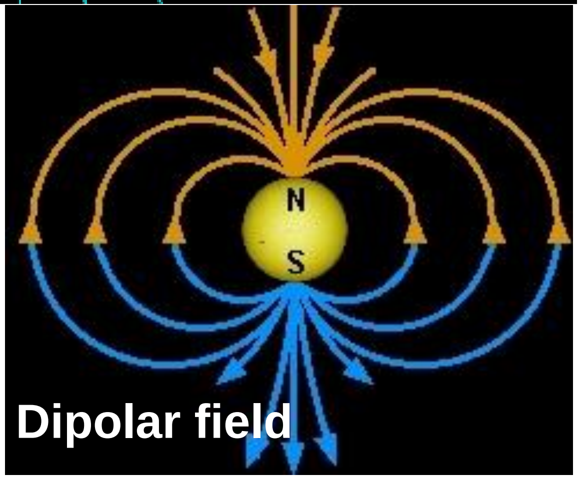
Observation of
sunspots today
Soho images

Generation of a sunspot

Solar dipole field lines are distorted by the differential rotation of sun => magnetic loops which are sunspots



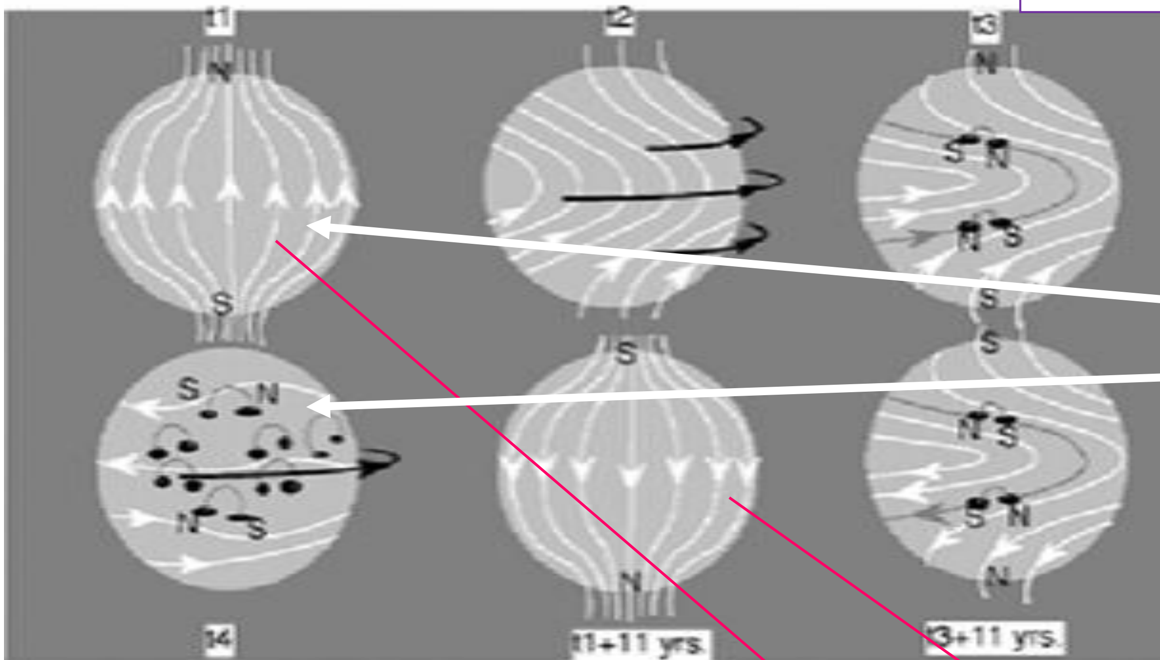




Multipolar field – Toroïdal field

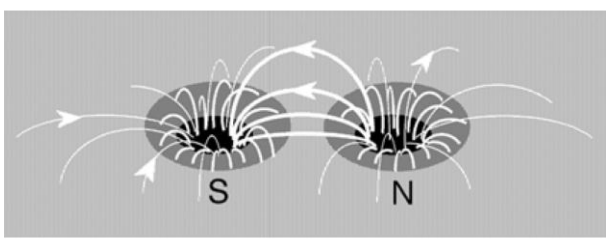
SOLAR DYNAMO

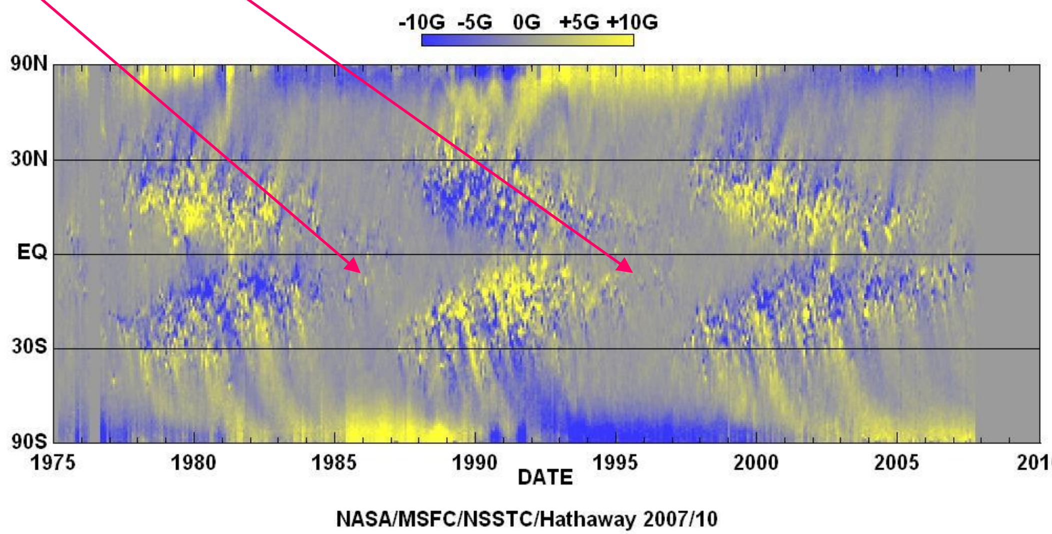
A sketch of the formation of sunspots and the 22-years sunspot cycle due to the differential rotion of plasma in the photosphere



Solar differential rotation

Dipolar and Toroïdal components

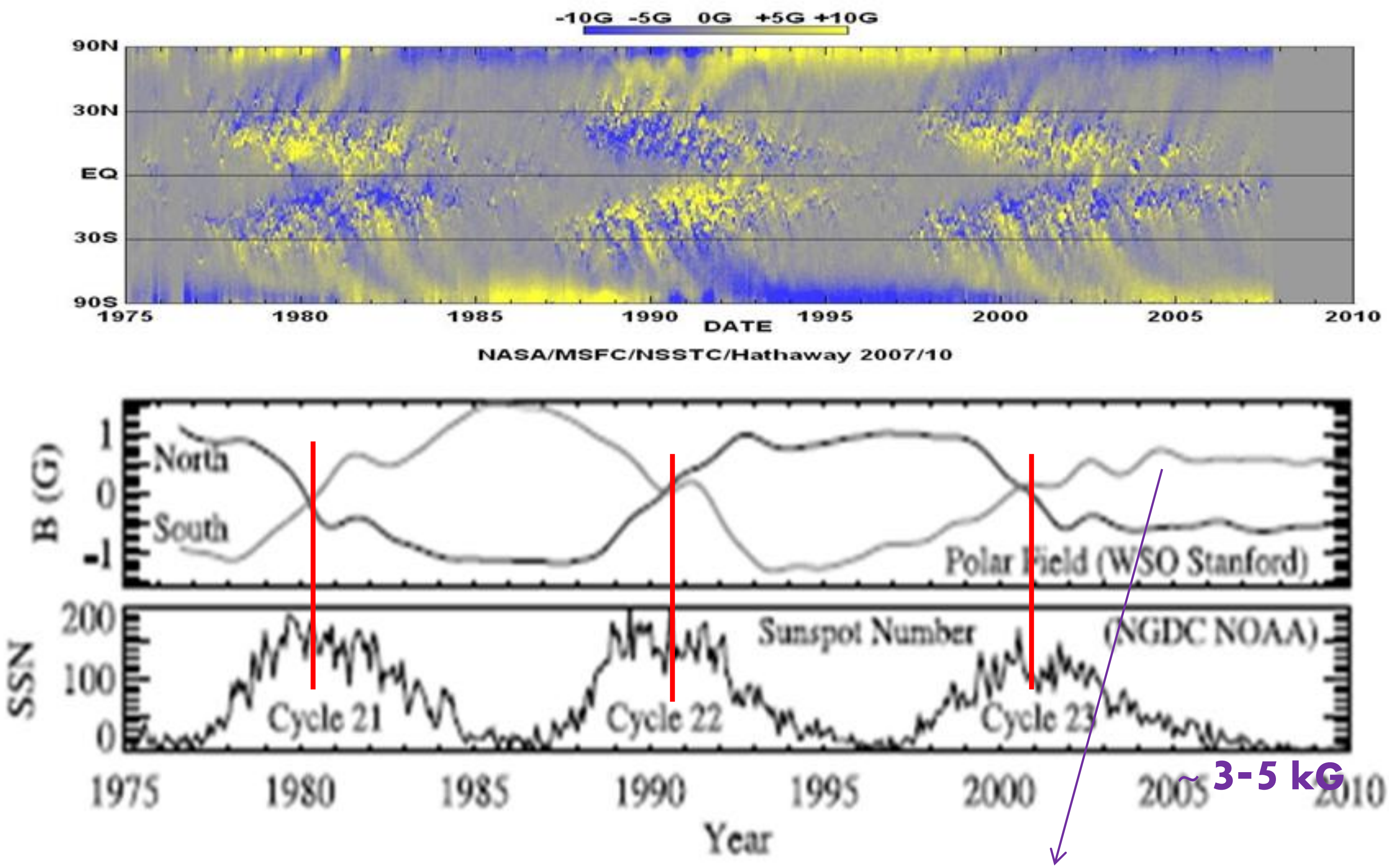




Yellow –outward /+
Blue – inward / -

http://solarscience.msf.nasa.gov/dynamo.shtml

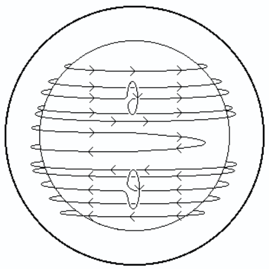
Solar impacts on the Earth depend on 2 components of the solar magnetic field



Decrease of the dipolar component of solar magnetic field

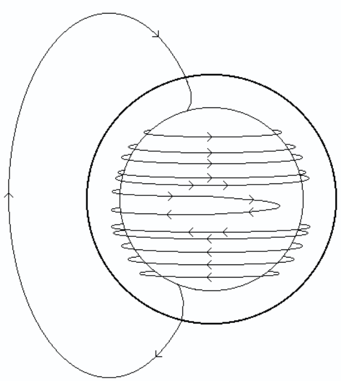
Luhmann et al., 2011

http://solarscience.msf.nasa.gov/dynamo.shtml



The α-effect

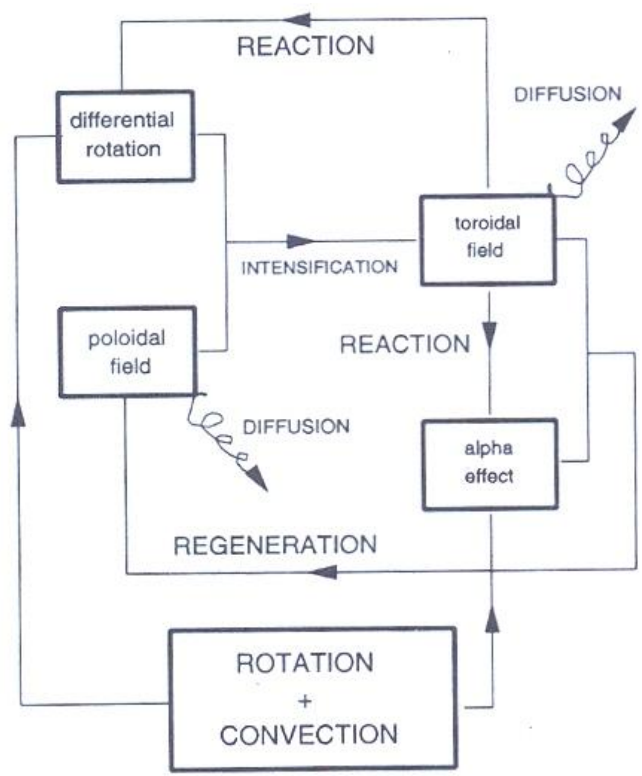
Twisting of the magnetic field lines is caused by the effects of the Sun's rotation



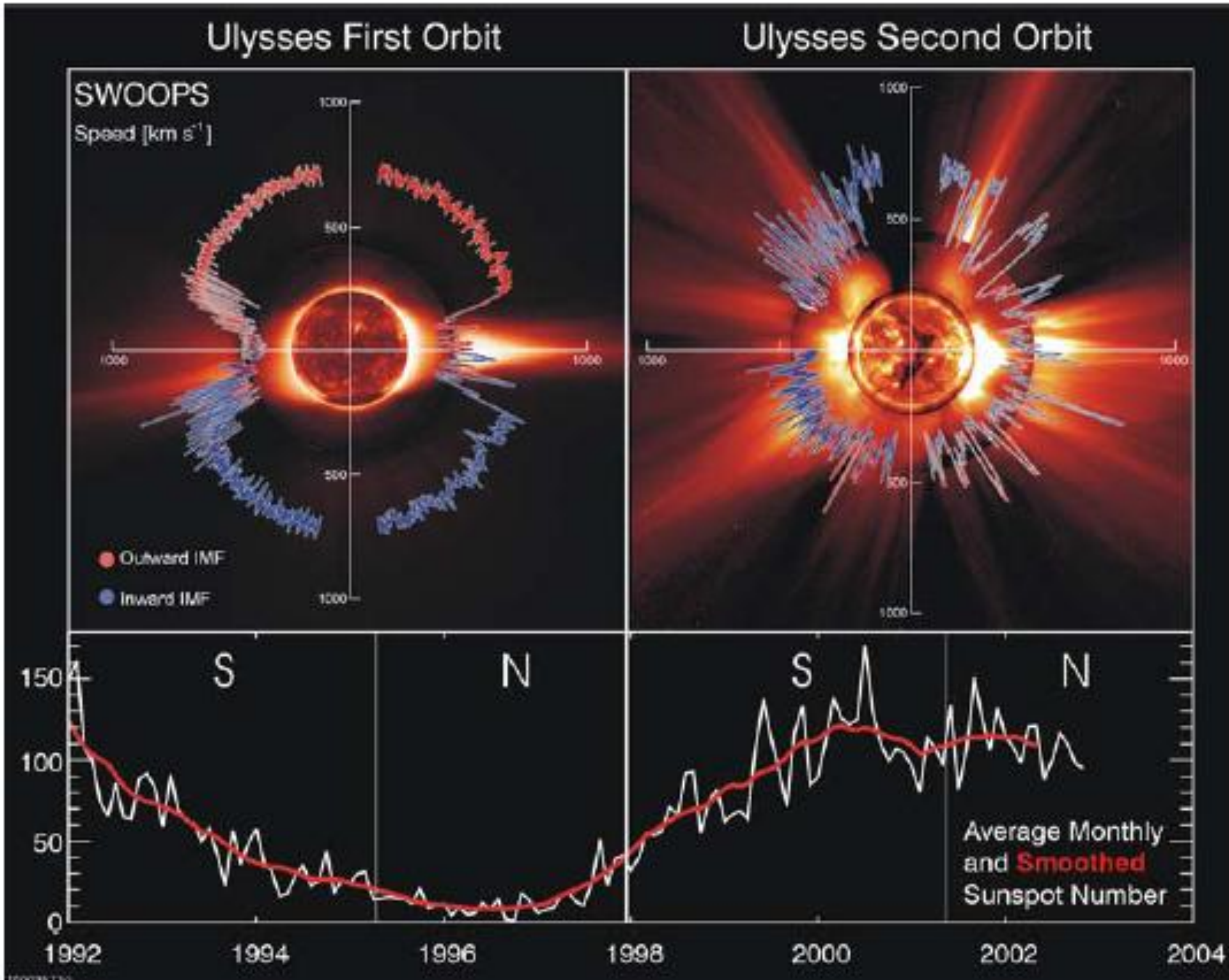
The ω-effect

Differential rotation change in rotation rate as a function of latitude and radius within the Sun $\omega(r,\theta)$

Diagram from L. Paterno, 2006



The solar dynamo ingredients
Motions : rotation and convection
Magnetic field : dipolar component

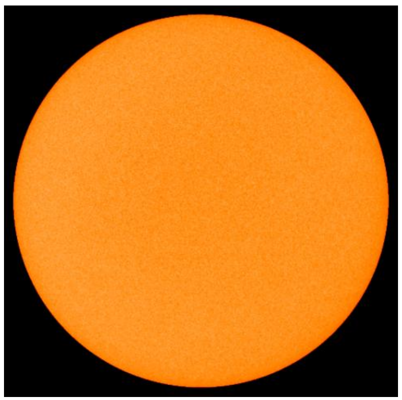


John Richardson, MIT

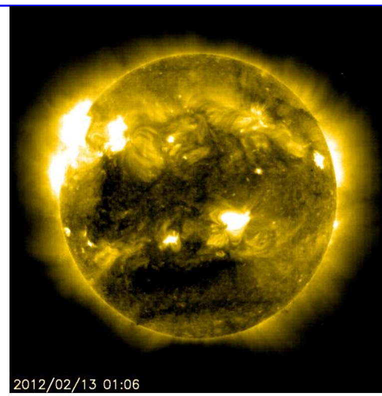
Improving of the classification of Legrand and Simon using Aa indices, SSC, Solar events and empirical relation between solar wind and geomagnetic indices

By J-L. ZERBO et al. (Annales Geophysicae 2012)

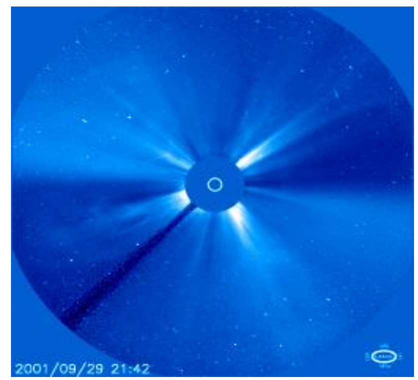
Aa < 20 nT
Quiet magnetic activity



Aa > 20 nT
Recurrent activity
High speed solar wind streams from coronal holes



Aa > 20 nT
Shock activity /SSC
CME



All the other cases are classified in the fluctuating activity ~ 20%

Corotating Moderate Activity

Recurrent Activity

01-Jan	1974														29	19	22	25	30	21	5	19	15	26	11	10	10
14-Jan	16	29	26	28	41	15	22	24	9	7	10	86	49	58	31	43	38	28	24	18	13	12	16	13	16	11	9
10-Feb	28	42	62	35	19	6	14	21	4	7	22	35	25	65	43	52	45	39	46	32	28	35	19	32	35	26	26
09- Mar	45	48	47	24	14	31	5	58	12	4	5	30	79	53	47	42	42	39	38	28	50	30	42	28	25	62	45
05- Apr	28	37	32	24	30	41	30	4	10	7	5	6	11	65	51	66	55	45	52	31	34	34	33	36	31	30	14
02- May	32	32	46	45	11	21	18	19	4	7	7	8	20	45	48	53	39	39	36	37	42	44	60	29	24	24	17
29- May	16	28	42	37	30	35	17	11	13	5	12	15	26	48	44	41	31	56	33	32	21	21	31	10	17	15	18
25- Jun	14	67	76	37	37	30	18	21	16	40	76	121	20	46	26	37	24	37	26	31	18	17	15	10	12	19	15
22-Jul	14	89	65	33	28	36	29	24	16	12	11	36	57	35	33	37	35	30	27	27	18	10	10	8	8	10	10
18- Aug	17	52	54	55	50	50	44	24	15	29	33	48	29	35	42	52	29	34	31	24	22	14	8	10	6	9	23
14- Sep	16	70	97	6	27	49	53	61	34	28	39	43	56	45	26	27	33	49	53	19	15	16	18	11	21	61	18
11-Oct	10	26	92	37	56	76	71	52	50	63	18	26	8	59	41	48	44	44	29	18	11	9	11	10	6	10	17
07- Nov	16	35	48	16	73	89	55	42	19	25	20	14	22	39	36	27	26	40	31	31	15	11	5	5	15	25	29
04- Dec	15	19	8	17	29	71	33	33	28	37	19	23	15	32	50	45	40	33	24	38	25	24	21	39	19	16	10
31- Dec	21																										

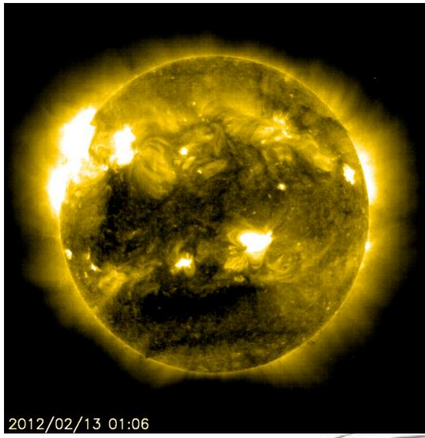
Aa(nT): 100, 60, 40, 30, 20, 10

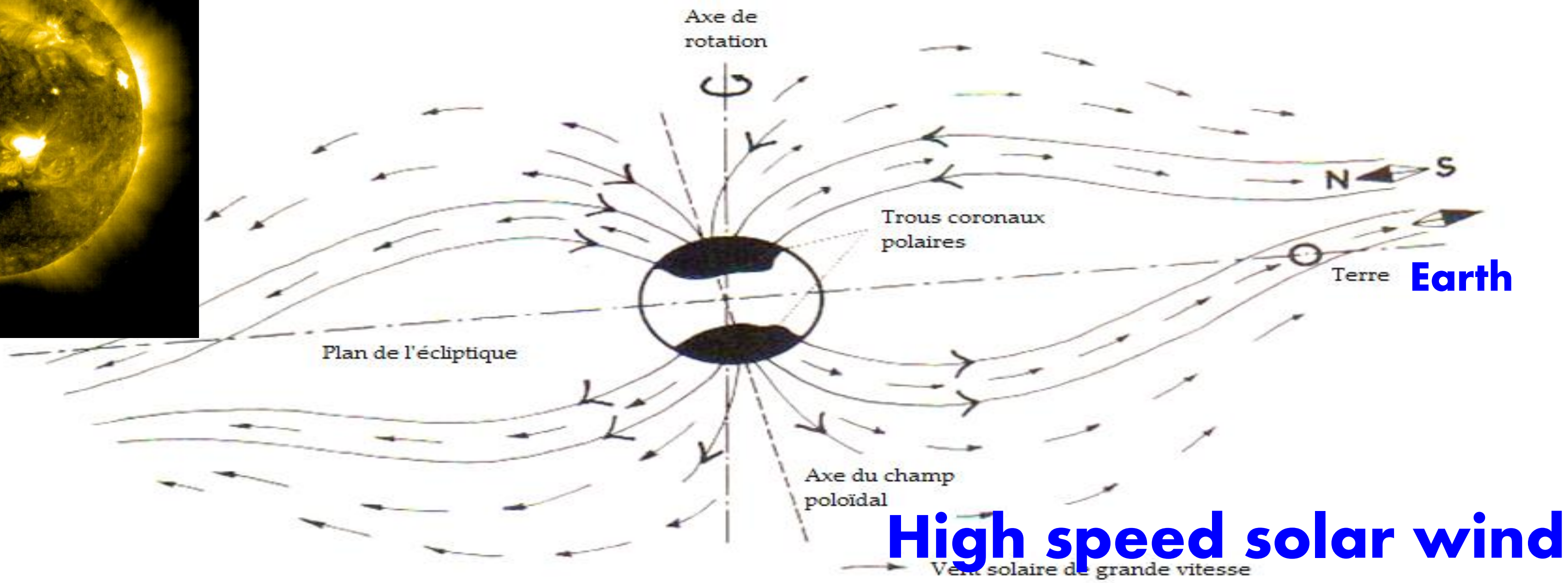
Shock Activity

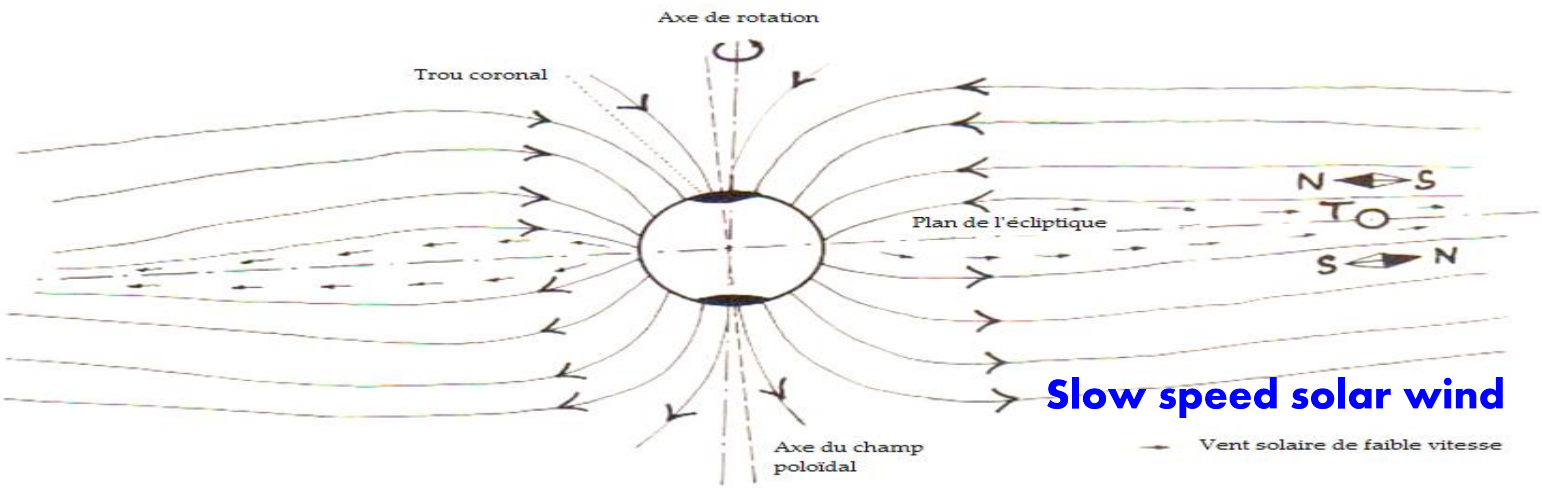
Cloud Shock Activity

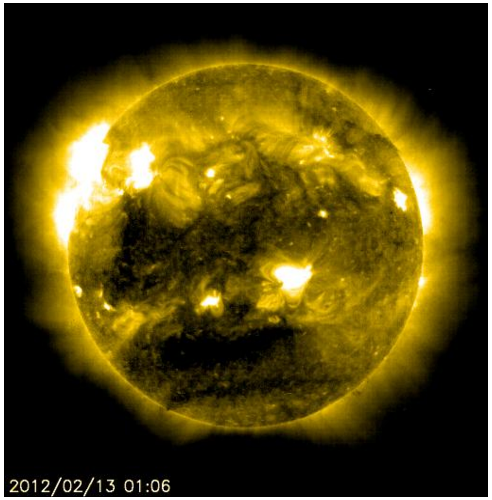
Quiet Activity

Coronal hole



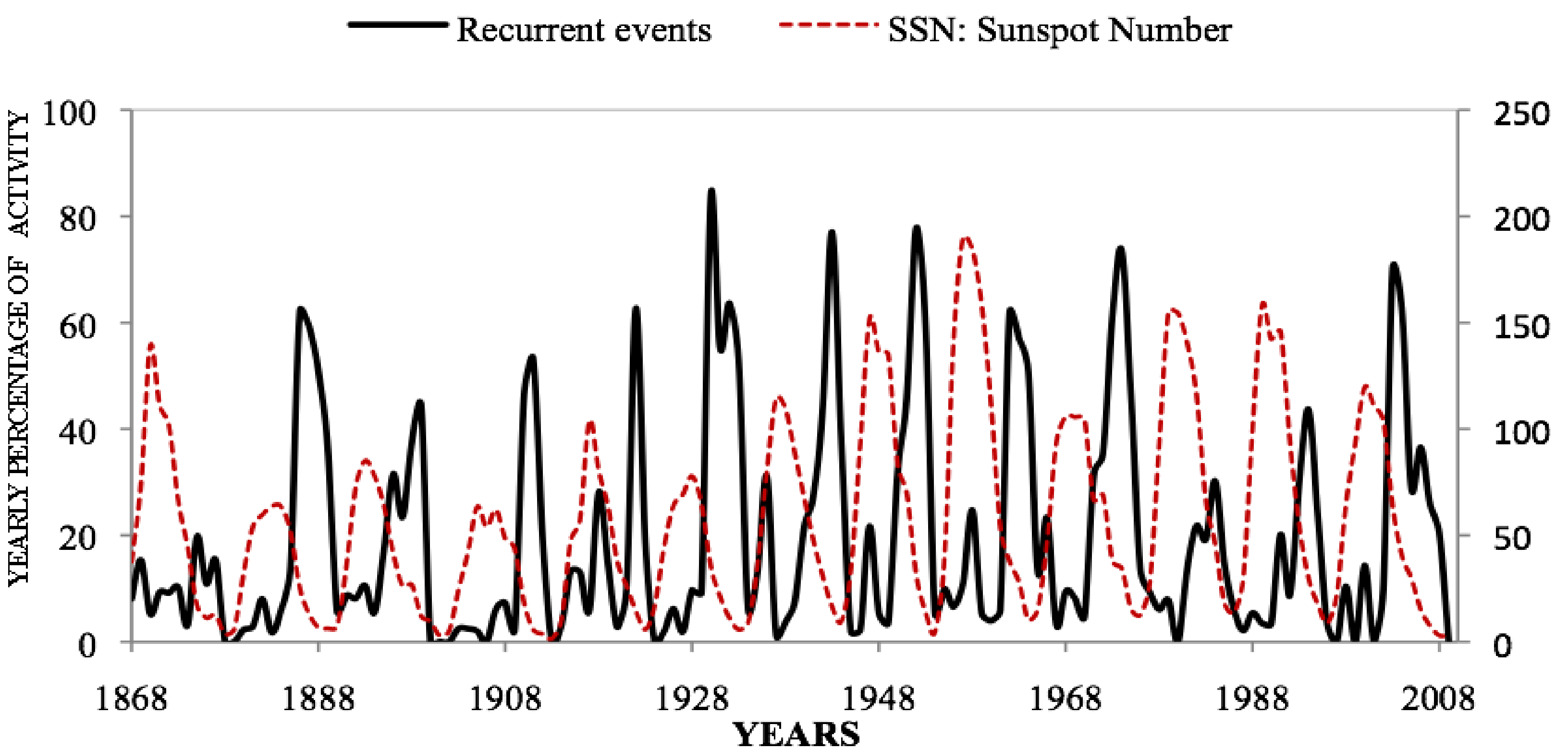


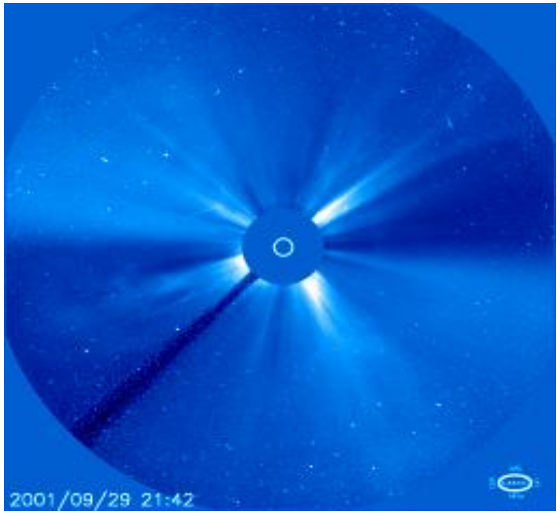




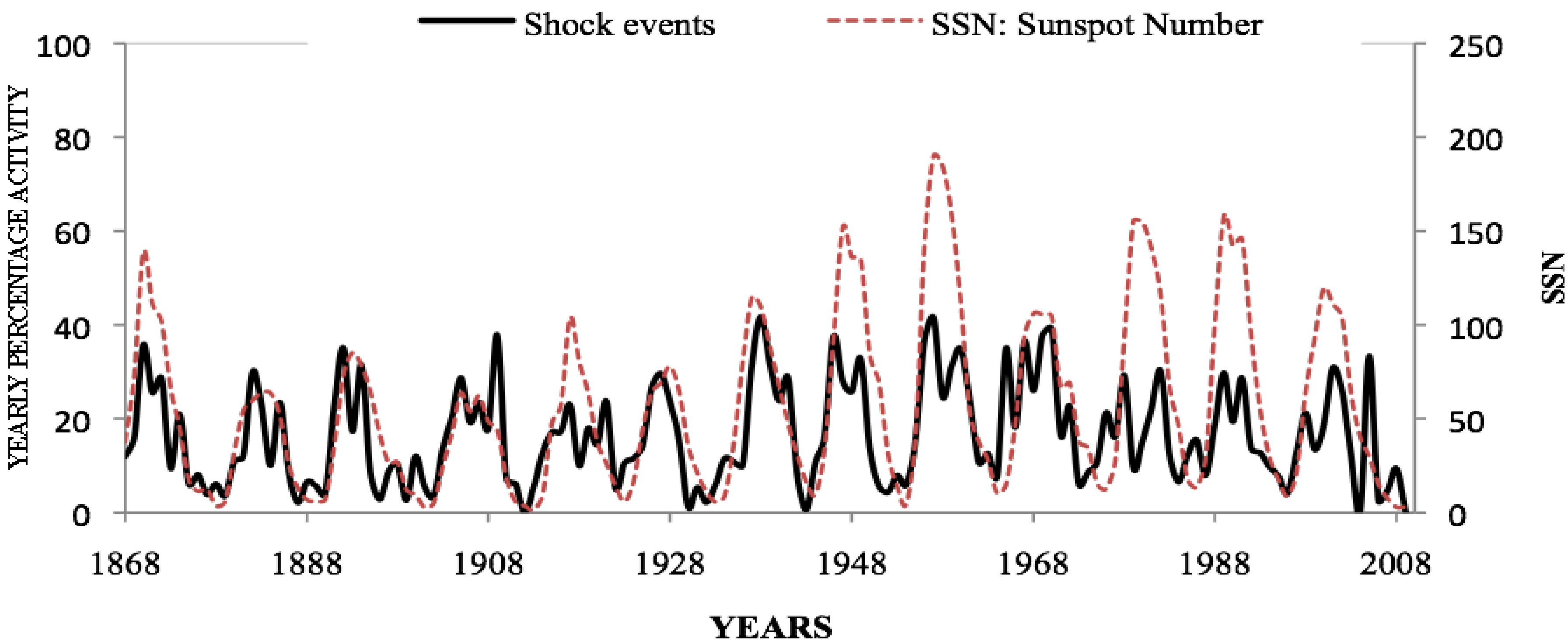
POLOIDAL FIELD
91,5% of geomagnetic activity
High speed solar wind streams flowing from coronal holes

Legrand and Simon, 1989
J-L. Zerbo et al., 2012



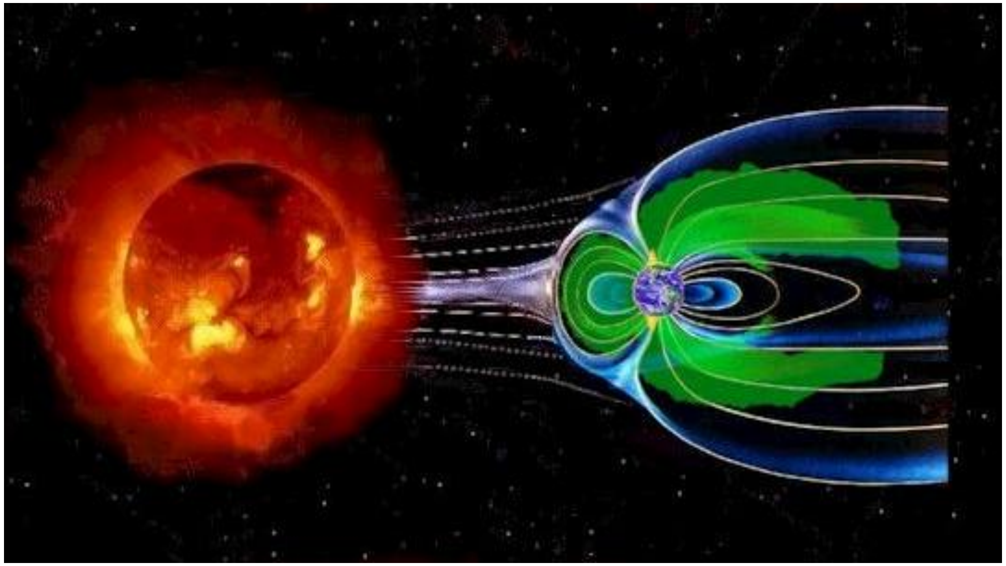


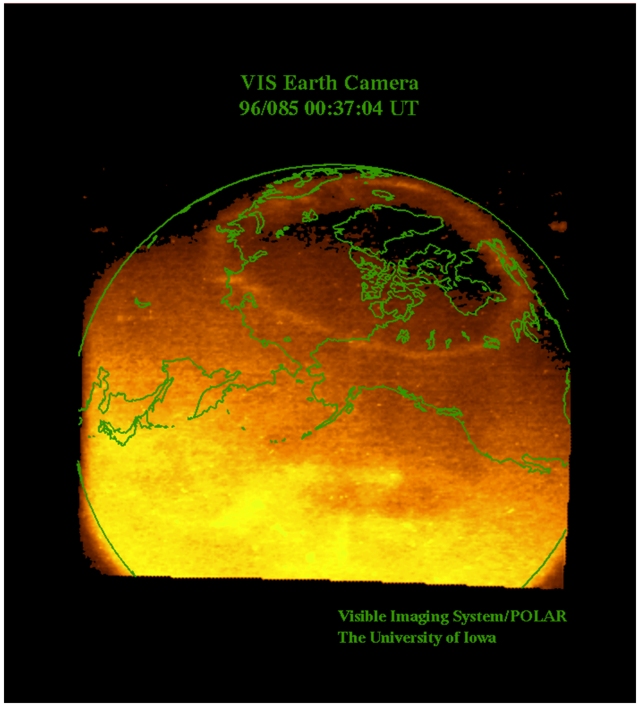
TOROIDAL FIELD
8,5% of geomagnetic activity
Shock events -> CME



Solar Wind – Magnetosphere Dynamo

The Solar wind magnetosphere Dynamo : Magnetic storm
Vs : Solar wind , Bi : interplanetary medium





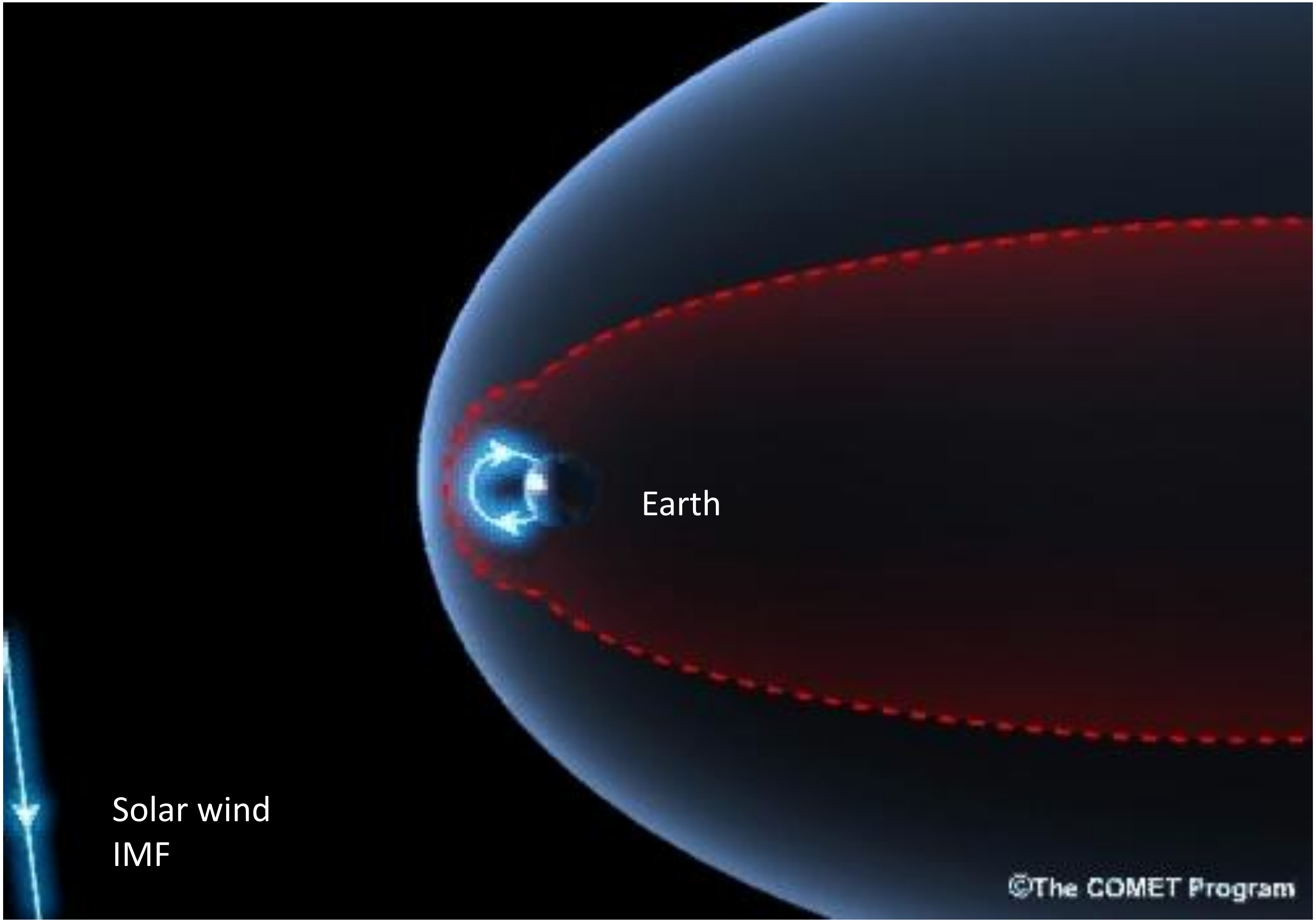
In the frame of the Magnetosphere

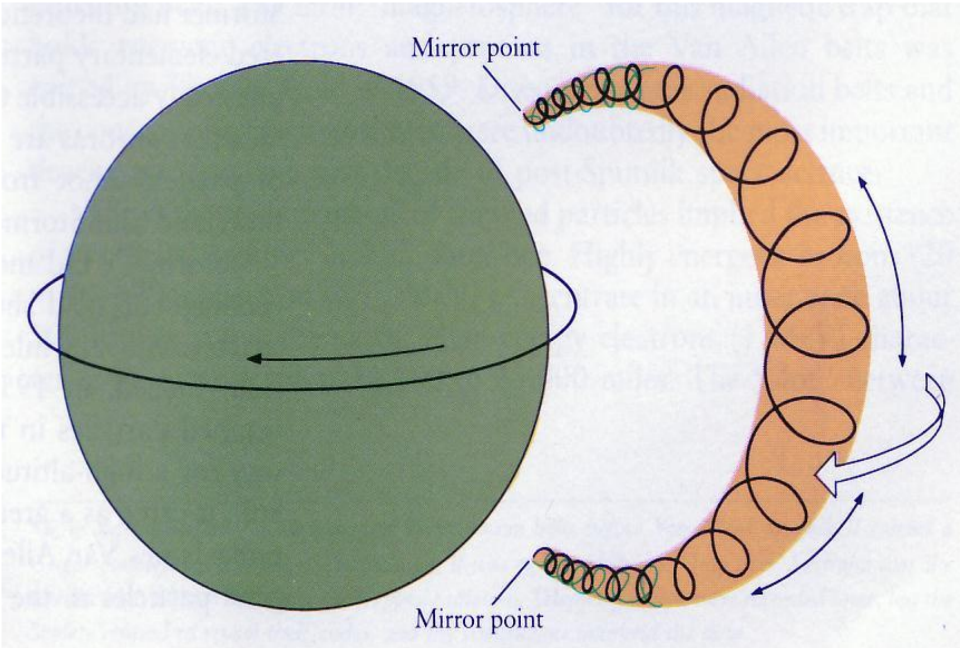
$$E = -V_s \times B_i$$

the components of the magnetic field that are perpendicular to the solar wind velocity are important

Component Bz of the interplanetary directed toward the south is a condition for a magnetic Storm in the majority of the Cases.

MAGNETIC RECONNECTION (Dungey, 1961)

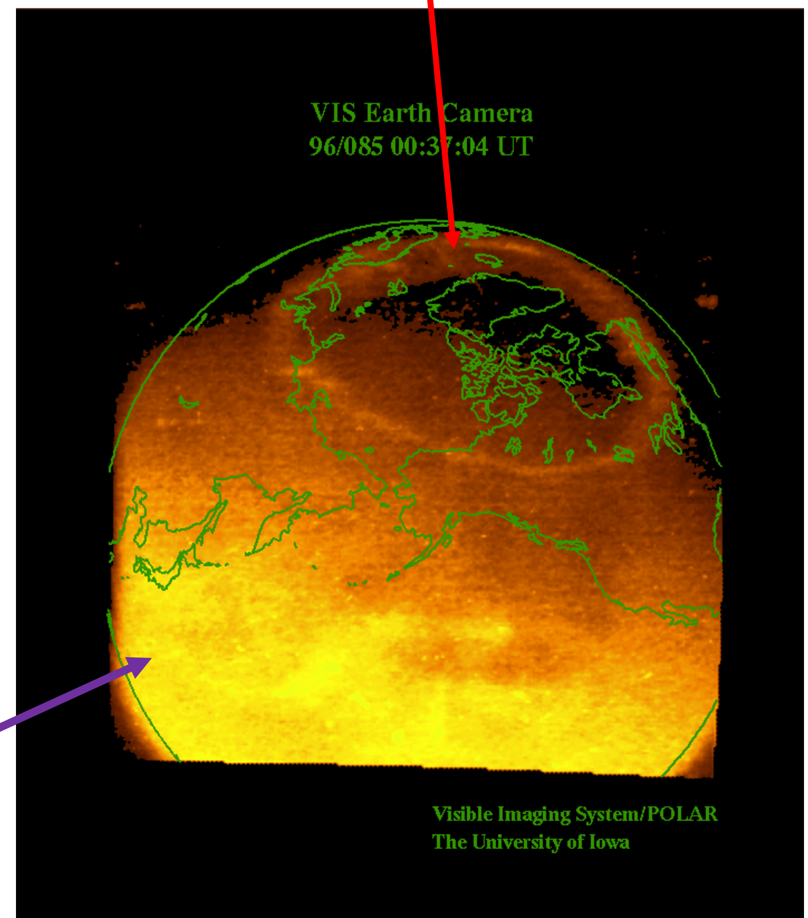




Friedman, 1987

Motion of the electric particules in the Earth magnetic field
There are precipitations of particules
In the auroral zone

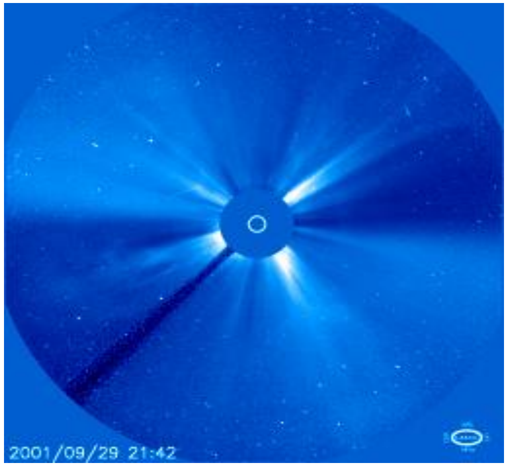
Photo of the auroral zone

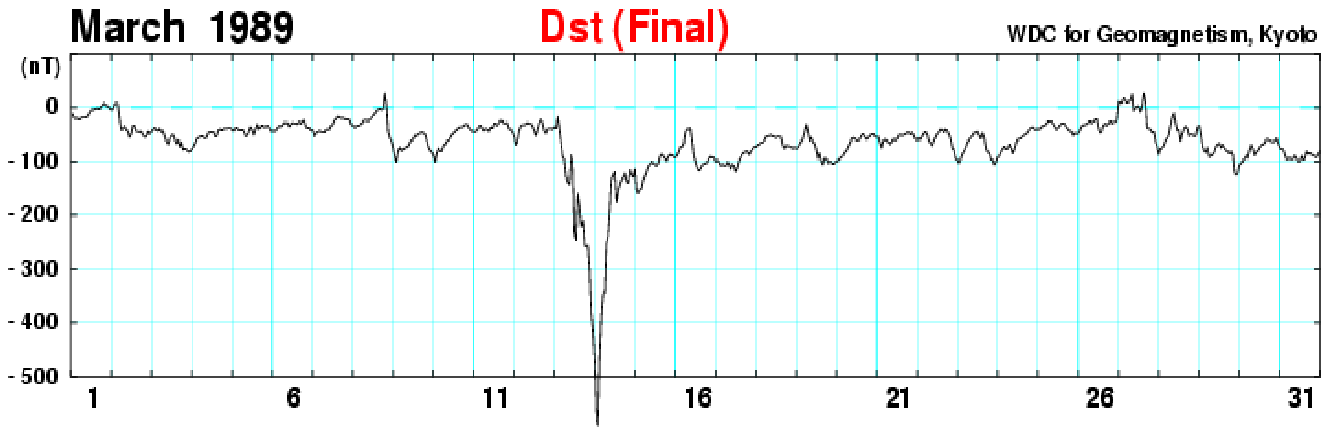


Solar Radiations

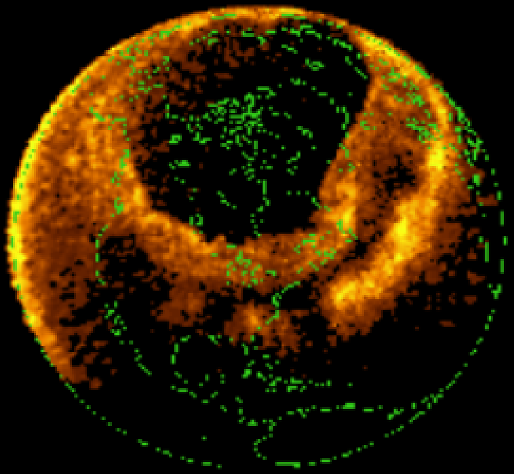
MAGNETIC STORM OF MARCH 15, 1989

the auroral oval extends toward low latitudes





Power failure



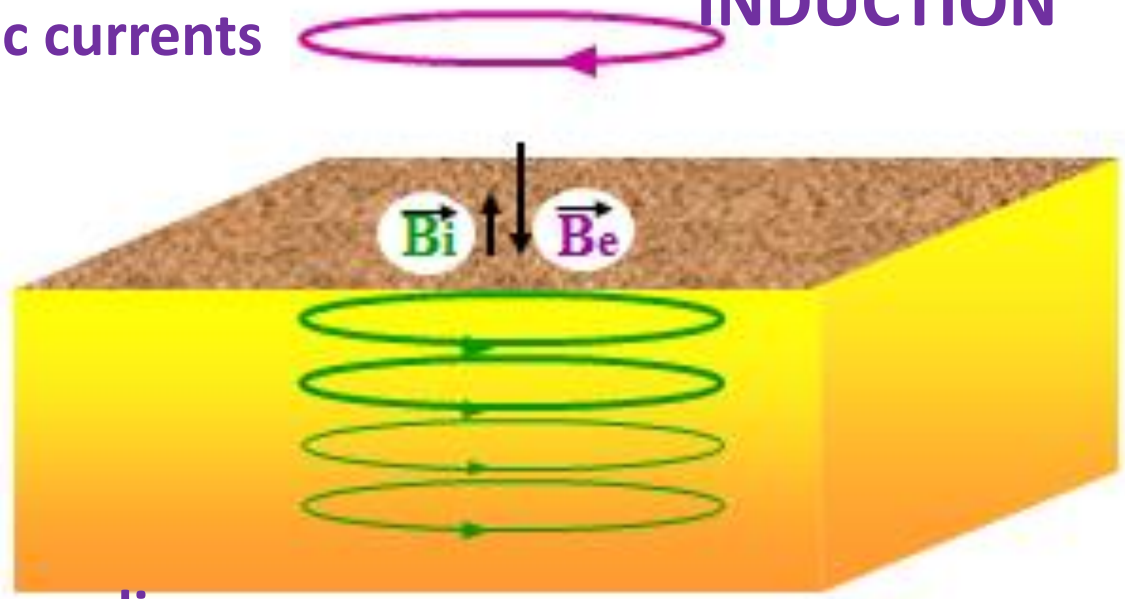
March 13, 1989 - The Quebec Blackout Storm - Most newspapers that reported this event considered the spectacular aurora to be the most newsworthy aspect of the storm. Seen as far south as Florida and Cuba, the vast majority of people in the Northern Hemisphere had never seen such a spectacle in recent memory. Electrical ground currents created by the magnetic storm found their way into the power grid of the Hydro-Quebec Power Authority and the entire Quebec power grid collapsed. Six million people were affected as they woke to find no electricity to see them through a cold Quebec wintry night. This storm could easily have been a $6 billion catastrophe affecting most US East Coast cities.

External electric currents systems are complex they involved

Sun, Solar Wind, Magnetosphere, Ionosphere, Atmosphere

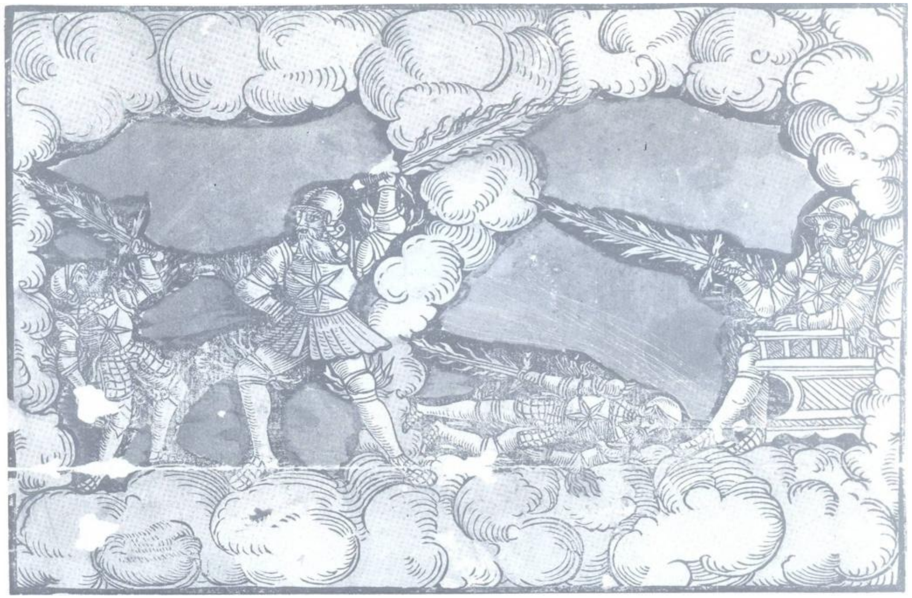
INDUCTION

External electric currents



Magnetotelluric soundings

GIC : Ground Induced Current => power failure
Use in prospection (Geology)



Picture of the By aurorae observed on Jule 24, 1554 in Germany and Switzerland
Legrand et al. 1991
The aurorae is at 100km height

Aurora observed at Rouen (near Paris)
On April 11 2001
During strong magnetic storms, the effects are observed at equatorial latitudes

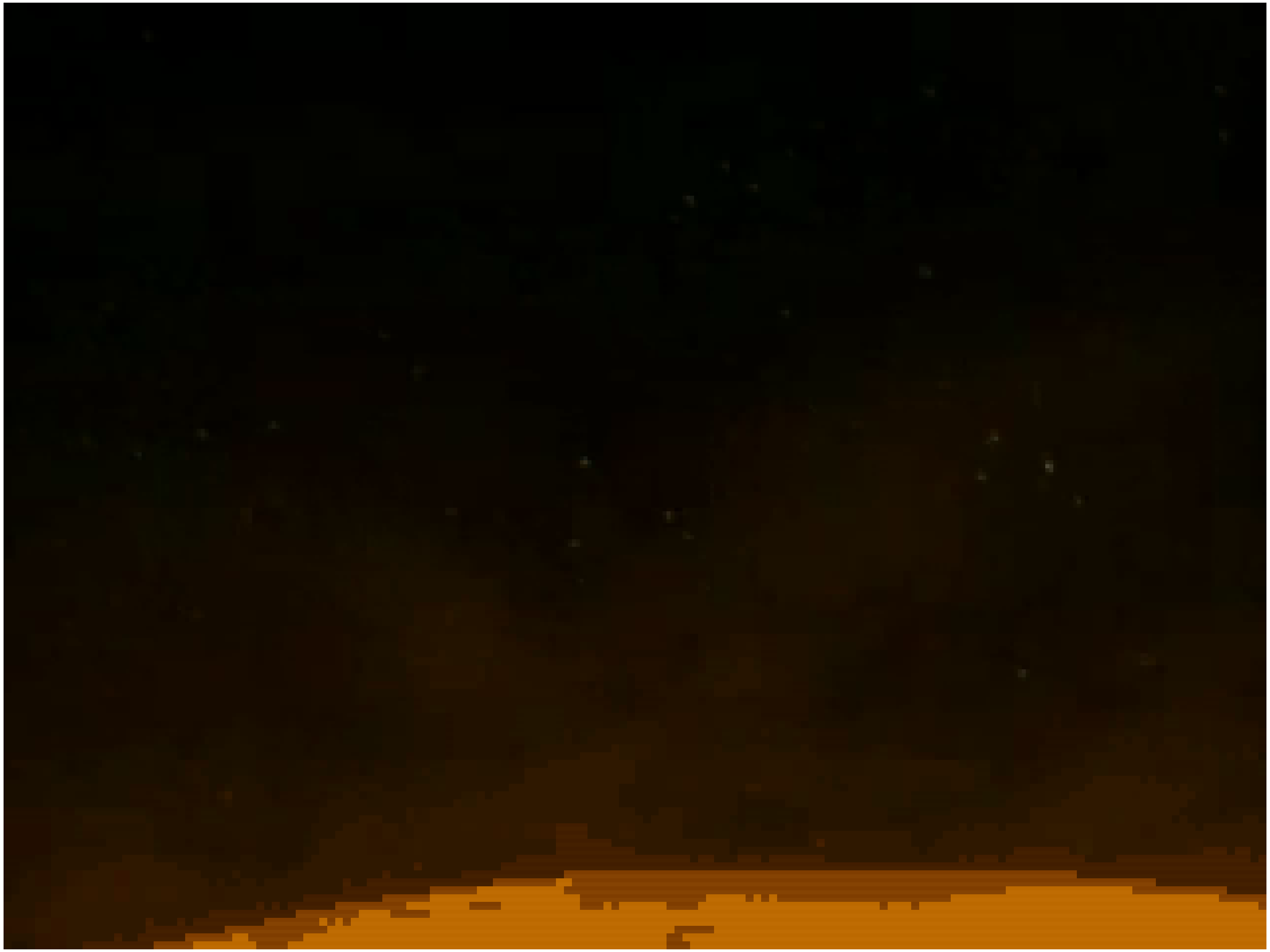
Jean DORTOUS DE MAIRAN -17 33
Academician -> reign of the king LOUIS XIV

Explained
the aurora

Aurora observed at Paris on May 13, 1869
(L'Atmosphere Flammarion)

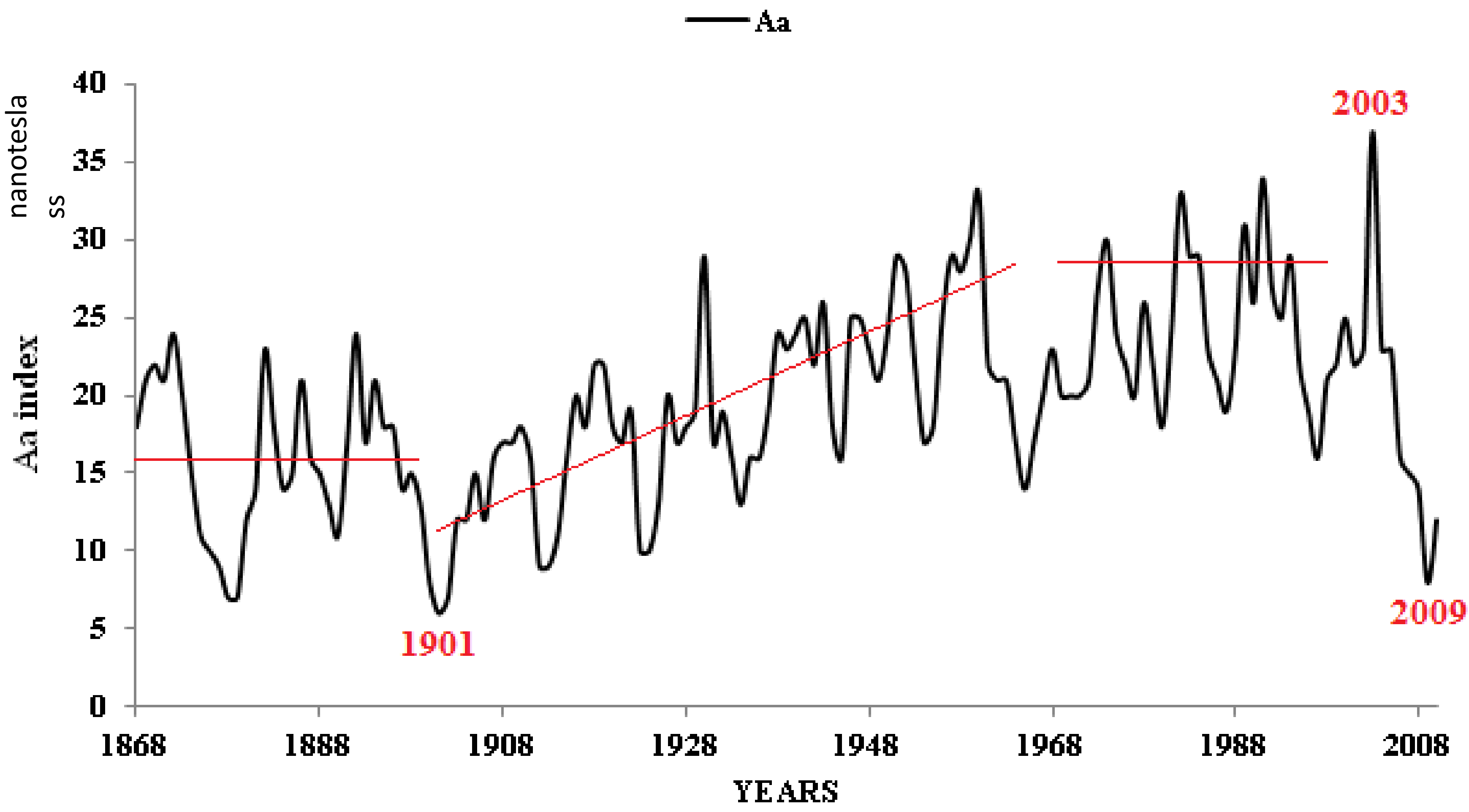
Arc auroral observed by A.E. Nordenskiold during his travel at Behring on March 21 1879
Les aurores polaires Angot, Paris 1895

Coronal Mass Ejection



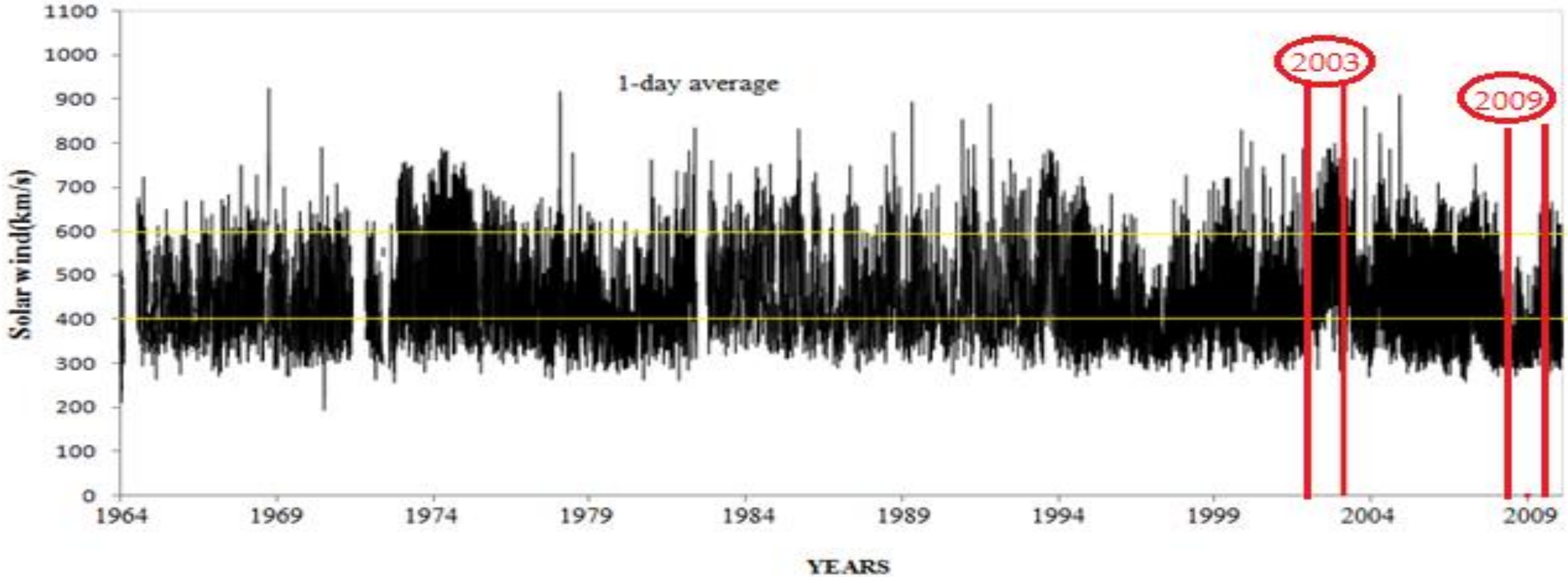
Billions tons of matter

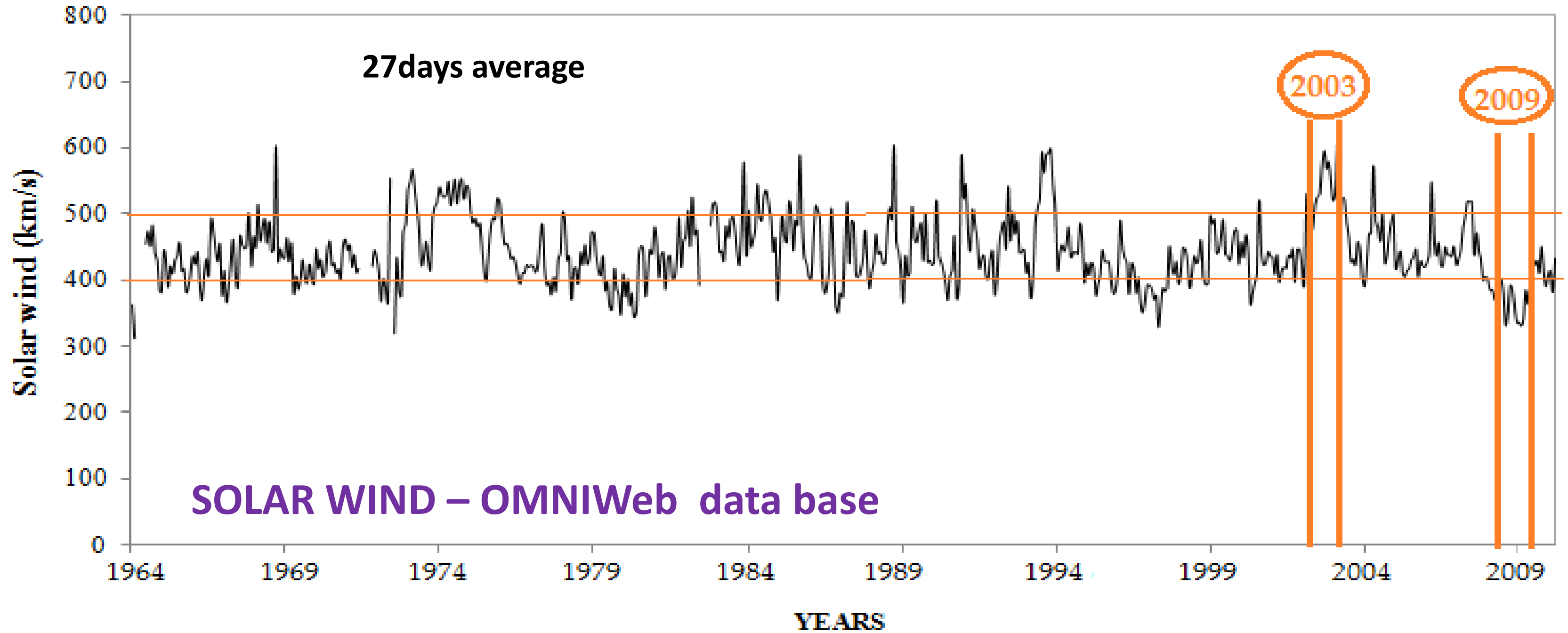
Exceptionnal years : long term variations



ISGI data base

Zerbo et al. , invited paper
Journal of Advanced Research 2012





Zerbo et al. , invited paper
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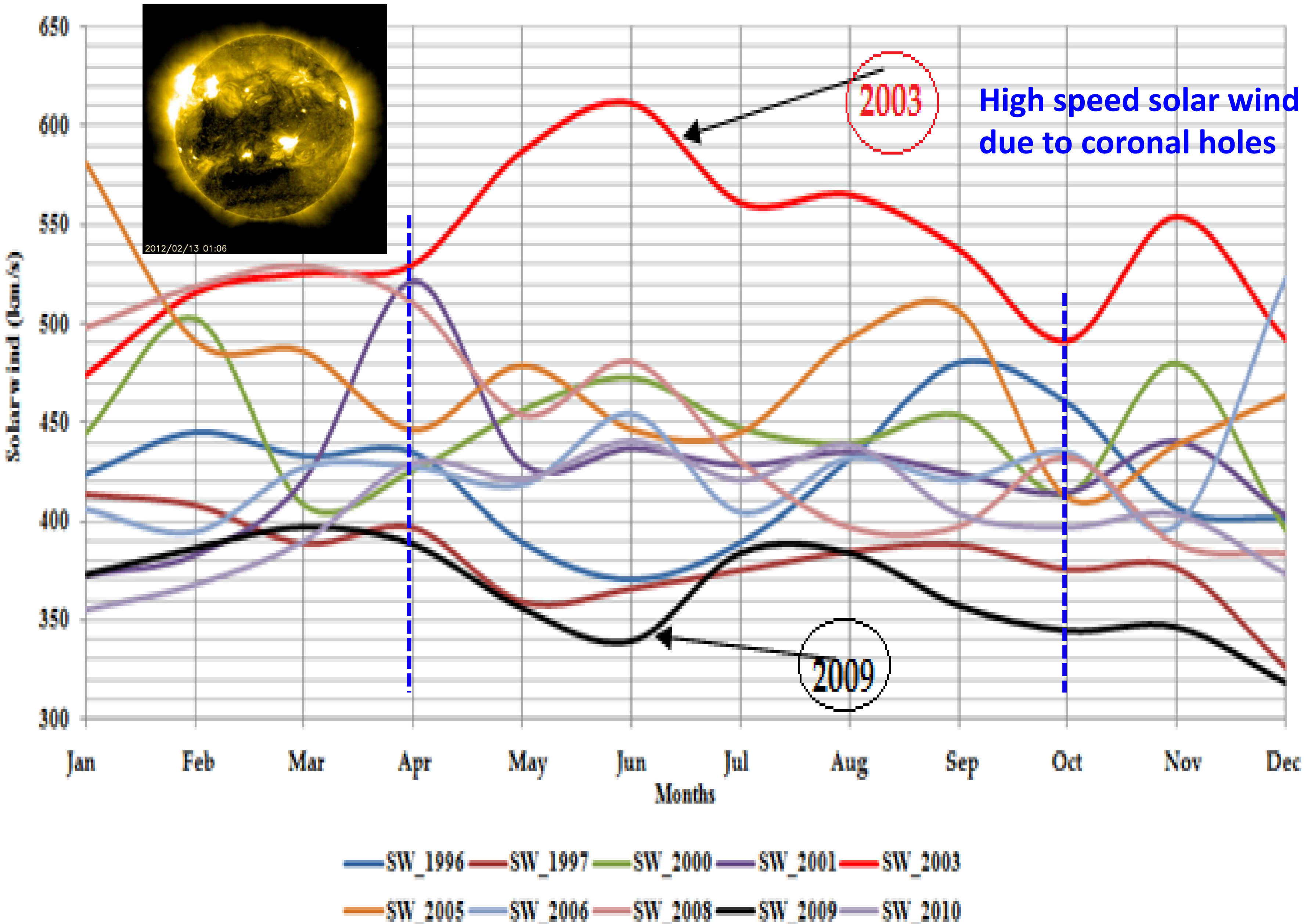
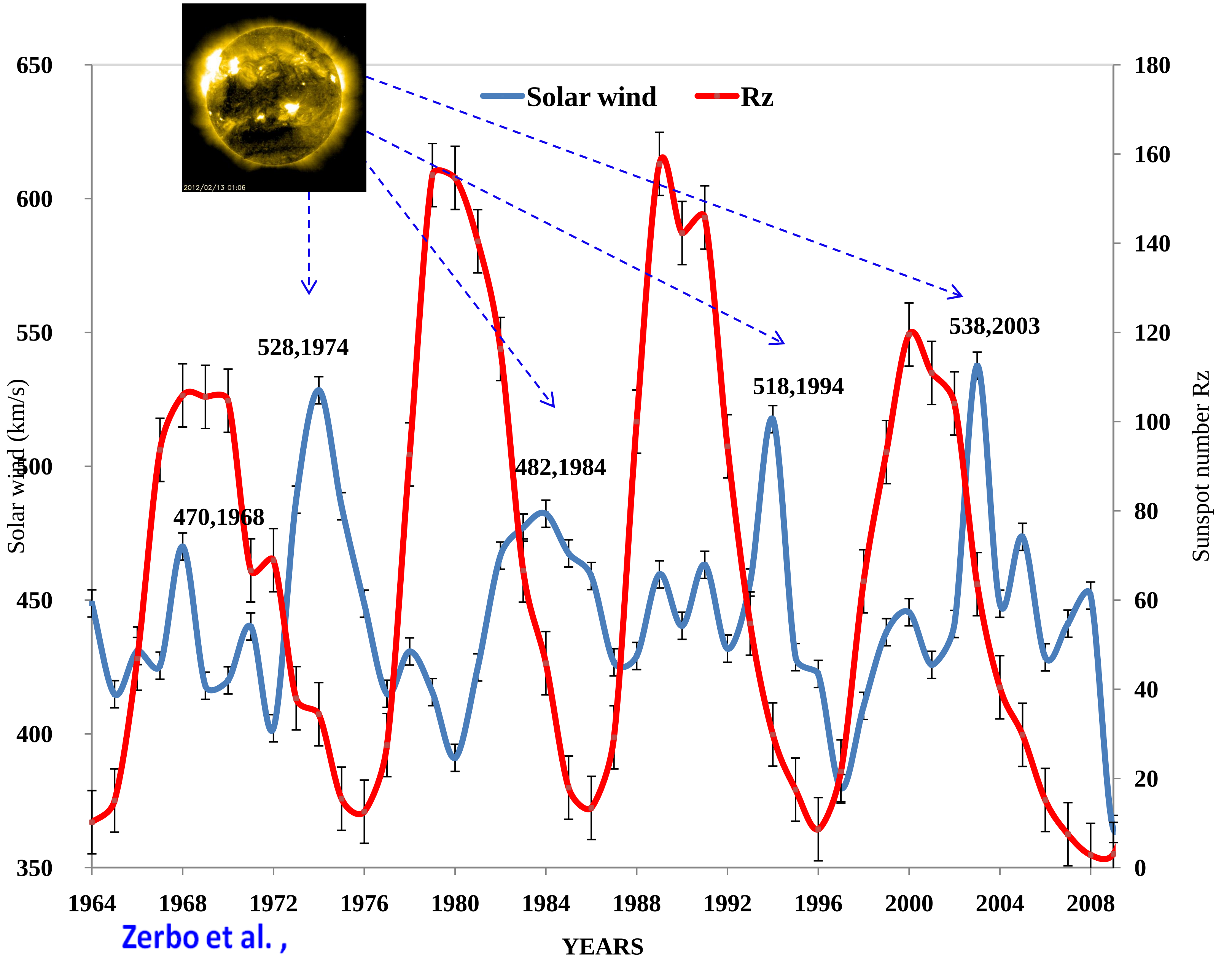
Zerbo et al. , Journal of Advanced Research 2012





Zerbo et al. ,
Journal of Advanced Research 2012

IONOSPHERIC DYNAMO

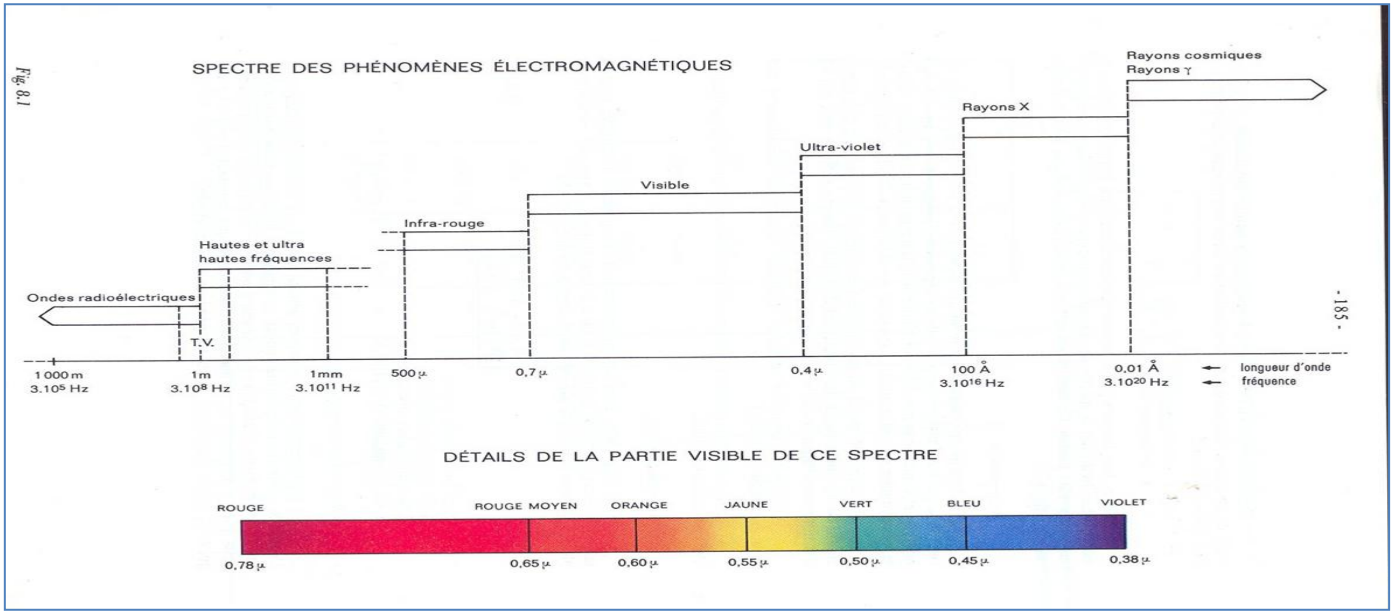
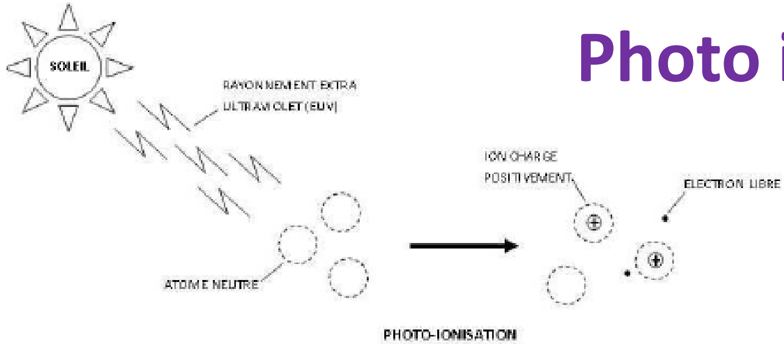


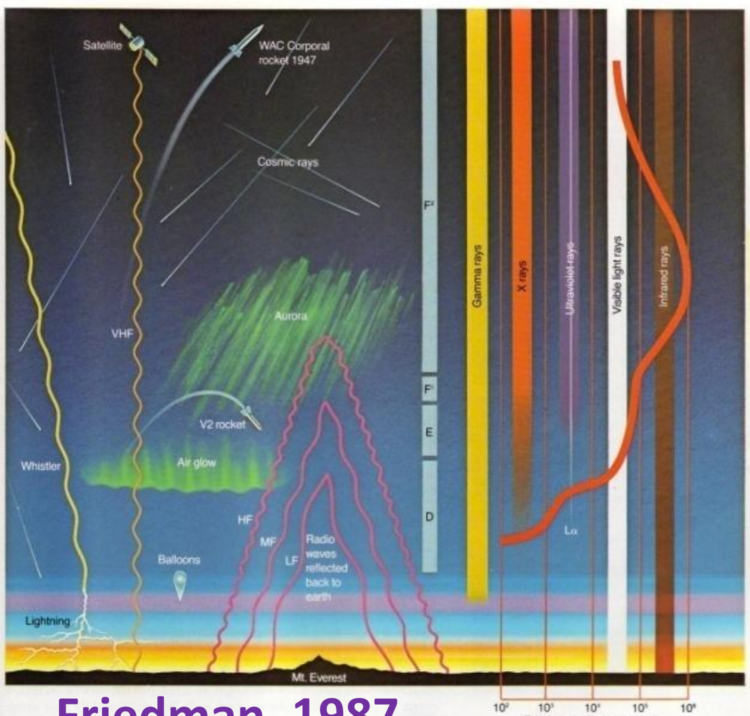
Photo ionisation



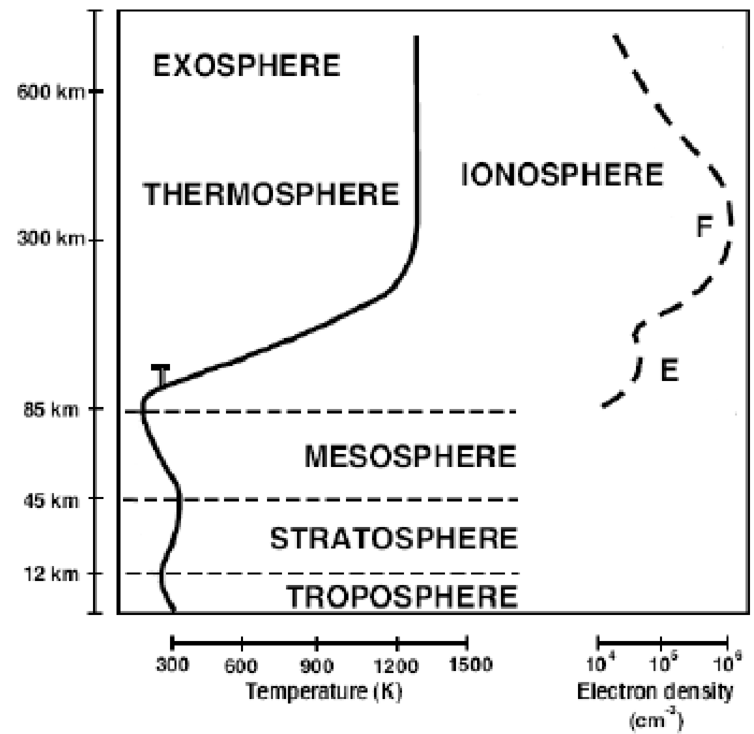
$$A \;\rightarrow\; A^{+} + e^{-}$$

FIGURE 1.6 – *Photoionisation d'un atome neutre A, par un rayonnement ultraviolet extrême (EUV) du soleil, produisant un ion chargé positivement A^+ et un électron libre e^-.*

IONOSPHERIC DYNAMO
SOLAR RADIATIONS
UV , EUV



Friedman, 1987



IONOSPHERIC DYNAMO (Stewart 1882)

Motion of the neutral atmosphere

V_n

B_t

Earth's magnetic field

DYNAMO electric field

$V_n x B_t$

E

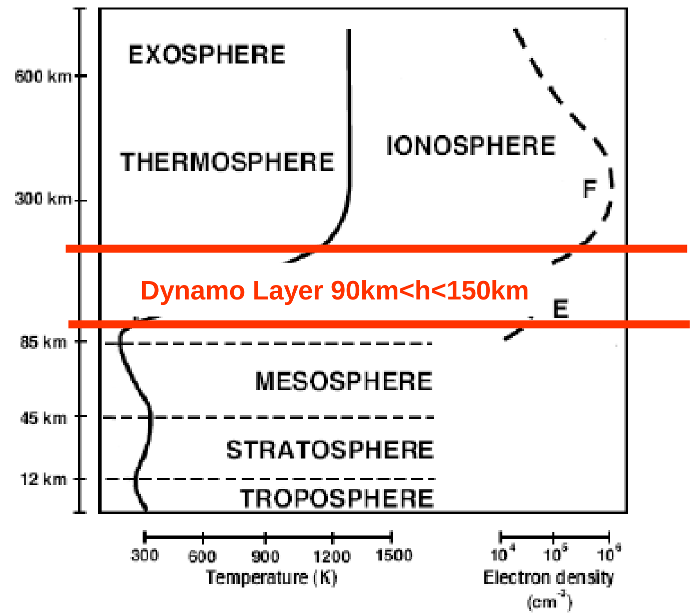
POLARISATION electric field

IONOSPHERIC OHM'S LAW

$$\vec{J} = \sigma_p\left(\vec{E}_\perp + \vec{V}_n \Lambda \vec{B}\right) + \sigma_h \vec{b} \Lambda \left(\vec{E}_\perp + \vec{V}_n \Lambda \vec{B}\right) + \sigma_{//} \vec{E}_{//}$$

$$\sigma_p = \frac{N_e e}{B}\left(\frac{\nu_{in}\Omega_i}{\nu_{in}^2 + \Omega_i^2} + \frac{\nu_{en}\Omega_e}{\nu_{en}^2 + \Omega_e^2}\right)$$

$$\sigma_h = \frac{N_e e}{B}\left(\frac{\Omega_e^2}{\nu_{en}^2 + \Omega_e^2} - \frac{\Omega_i^2}{\nu_{in}^2 + \Omega_i^2}\right)$$



$$\Omega_e = \frac{eB}{m_e} \quad \Omega_i = \frac{eB}{m_i}$$

Gyrofrequencies of electrons ans ions

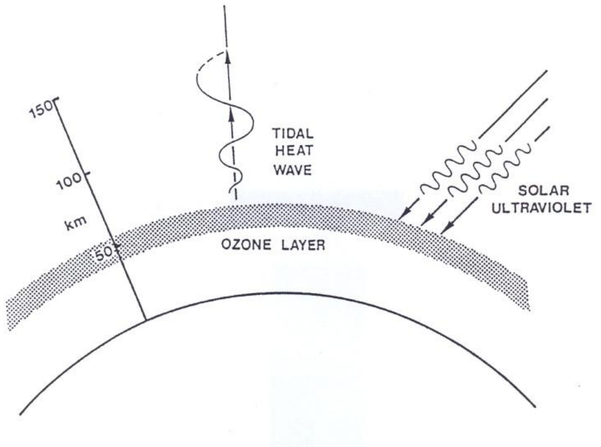
σ_p: Pedersen conductivity ⊥ B et // E

σ_h: Hall conductivity ⊥ B et E

υ_{in} et υ_{en}: collisions frequencies

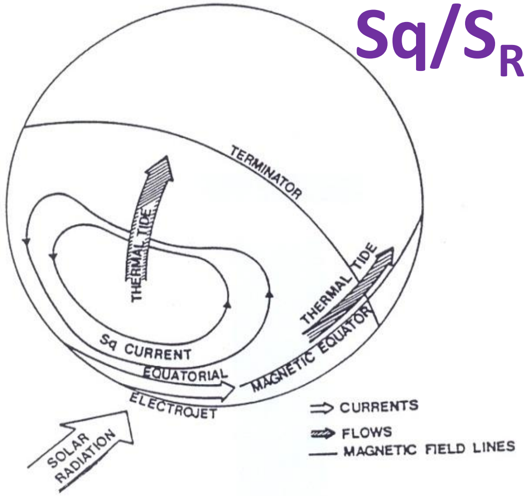
IONOSPHERIC DYNAMO / Neutral winds

Stratosphere Atmospheric Tides , Evans 1977

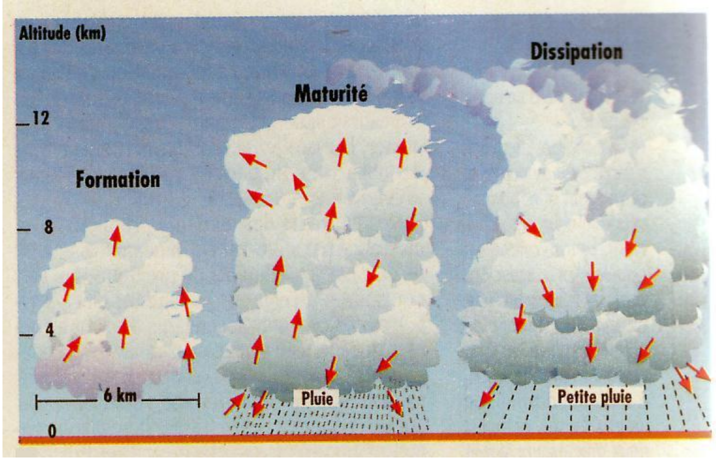


Diurnal process
E Region of the
Ionosphere
(90km< h< 150km)

Sq/S_R



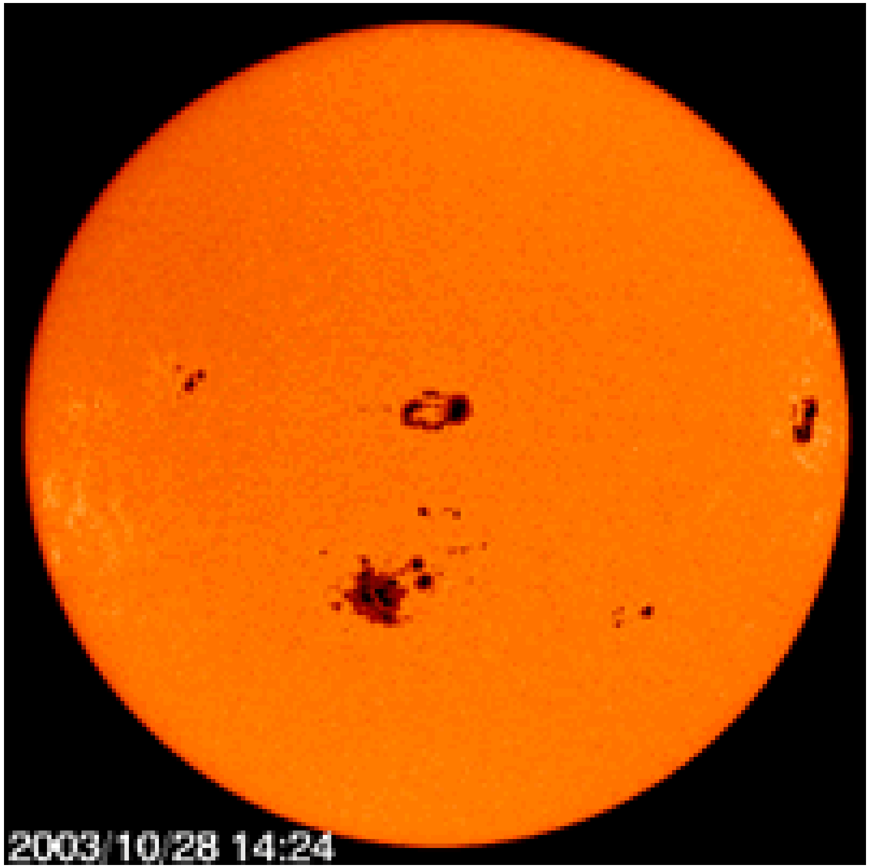
Deep convection in the troposphere : non migrating tides



Vertical coupling
Stratosphere , troposphere
Atmospheric electricity
Earthquake
Etc…

Field to investigate

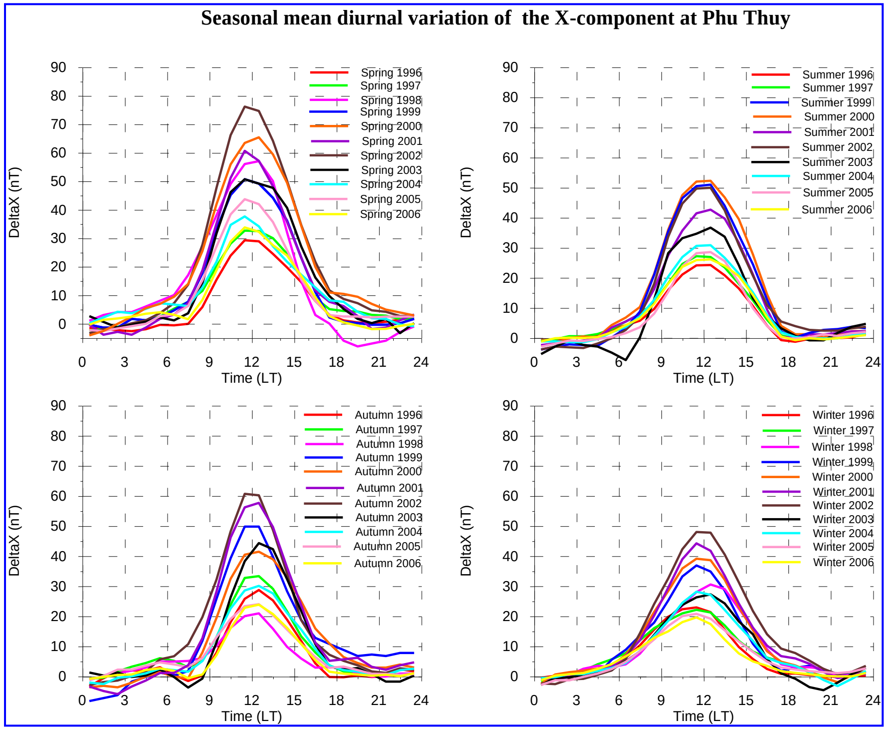
Sun Earth System



Images du satellite SOHO / NASA - ESA

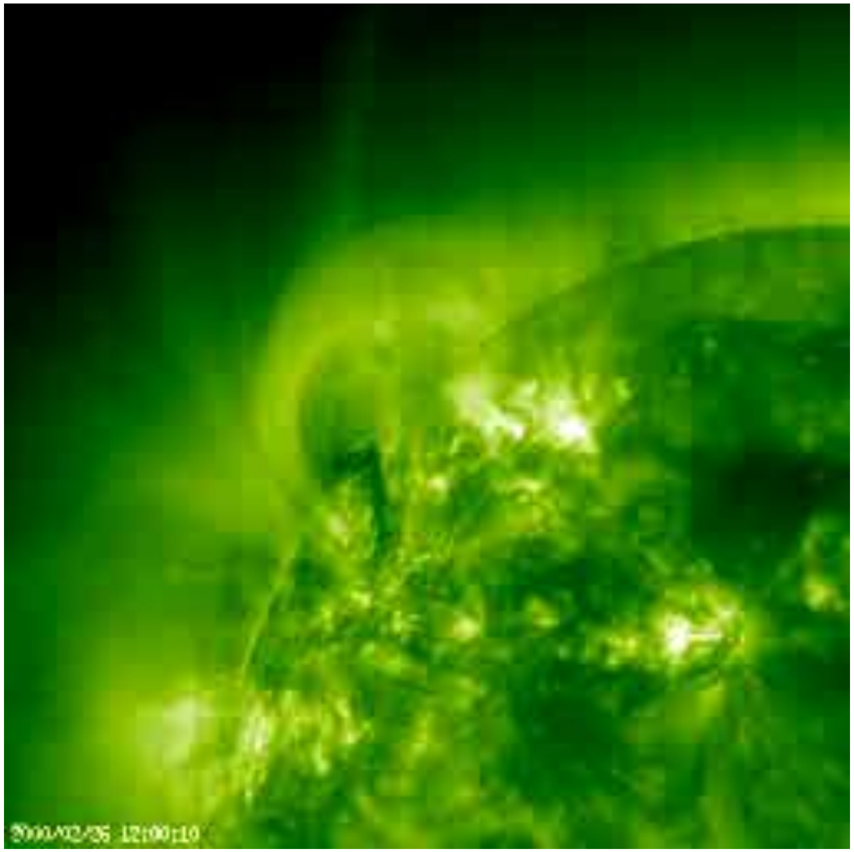
Sunspot
Solar Radiations EUV, UV

Regular variation of the Earth's magnetic Field at Phu Thuy/ Vietnam



Pham et al, Ann. Geophys. 2011

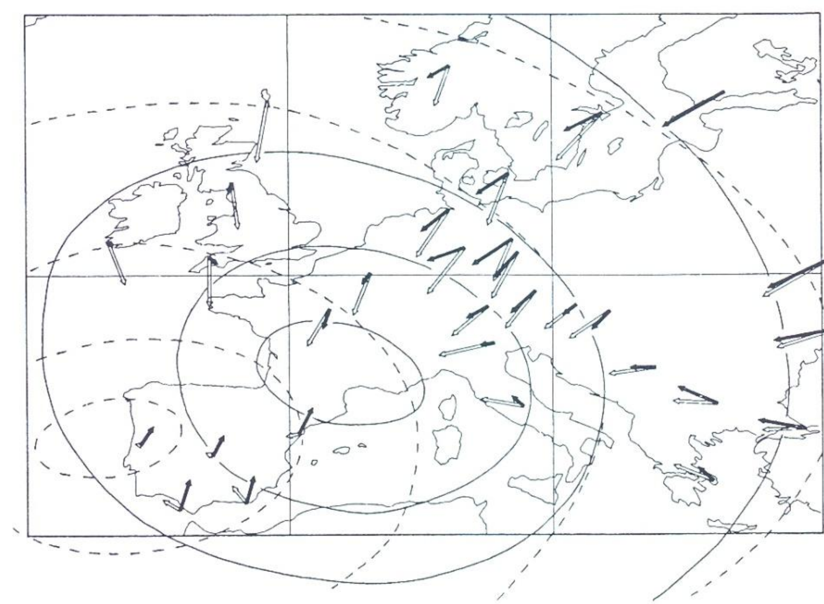
Solar flare affect directly the ionospheric dynamo



Images du satellite SOHO/NASA

Solar Flare -> Radiations X, EUV

Geomagnetic disturbance due to
A solar flare / black arrow



Curto et al.,JGR, 1994

Physics of the solar flare, PhD Curto 1992/ Curto et al. JGR, 1994

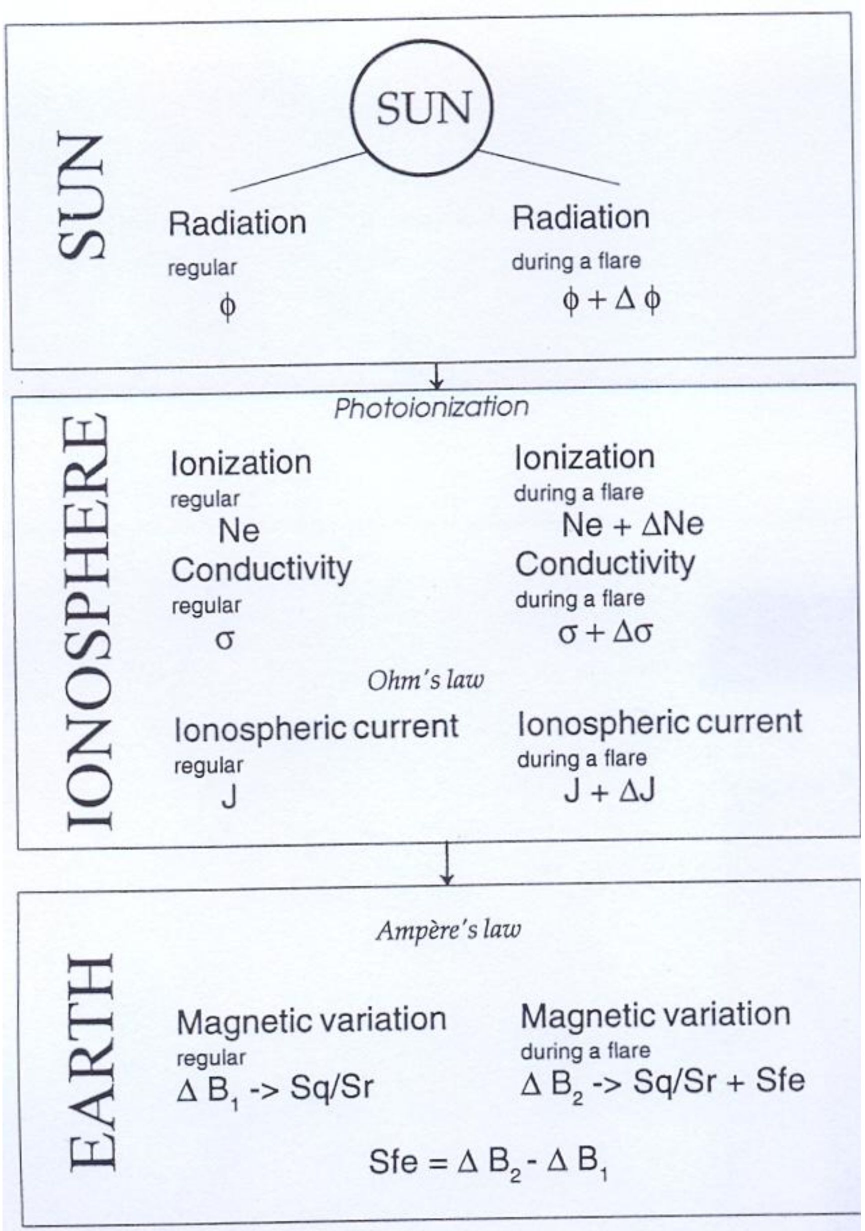
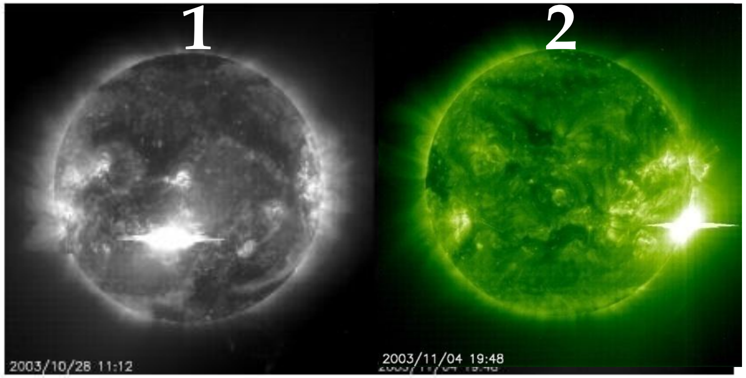


Table 1. Main Processes and Related Models Used.

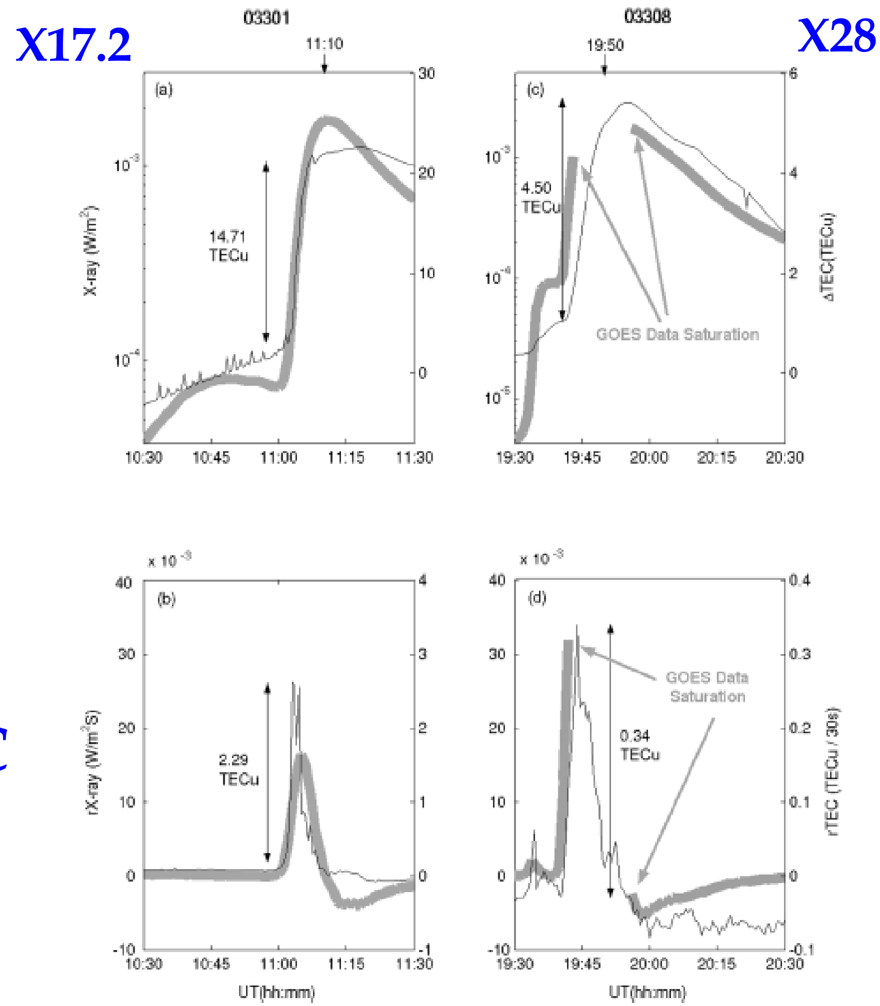
	Source
Sun Processes	
Models	
regular radiation flux	*Heroux et al.* [1974]
flare radiation flux	*Donnelly* [1976]
Ionosphere Processes	
Equations	
ion production rate	*Dymek* [1989]
continuity equation	*Dymek* [1989]
collision frequencies	*Stubbe* [1968]
Conductivity tensor (σ)	$\bar{\bar{\sigma}} = \begin{pmatrix} \sigma_P & \sigma_H & 0 \\ -\sigma_H & \sigma_P & 0 \\ 0 & 0 & \sigma_{//} \end{pmatrix}$
Ohm's law	$J = \sigma\,(E_p + V_n x B)$
Models	
Neutral composition	*Hedin* [1987]
Ion composition	*Oliver* [1975]
Electric fields (Ep)	*Blanc and Amayemc* [1979]
Neutral winds (Vn)	*Bernard* [1978]
Electric current	*Mazaudier and Blanc* [1982]
Ground Level Processes	
Ampere's law	$\Delta B = 2\pi/\ 10 f \int j dz$



2003/10/28 : 11h12   2003/11/04 : 19h48

SOHO Extreme ultraviolet Imaging Telescope (EIT) of the fourth largest (1) and the largest solar flare (2)

2003/10/28 : 11h12   2003/11/04 : 19h48



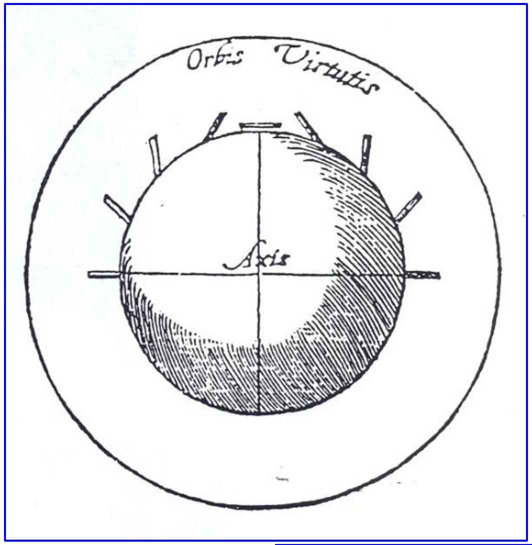
SOLAR FLARES AFFECT TEC

Liu et al, 2006, Solar flare signatures of the ionospheric GPS total electron content, JGR, vol 111, A05308

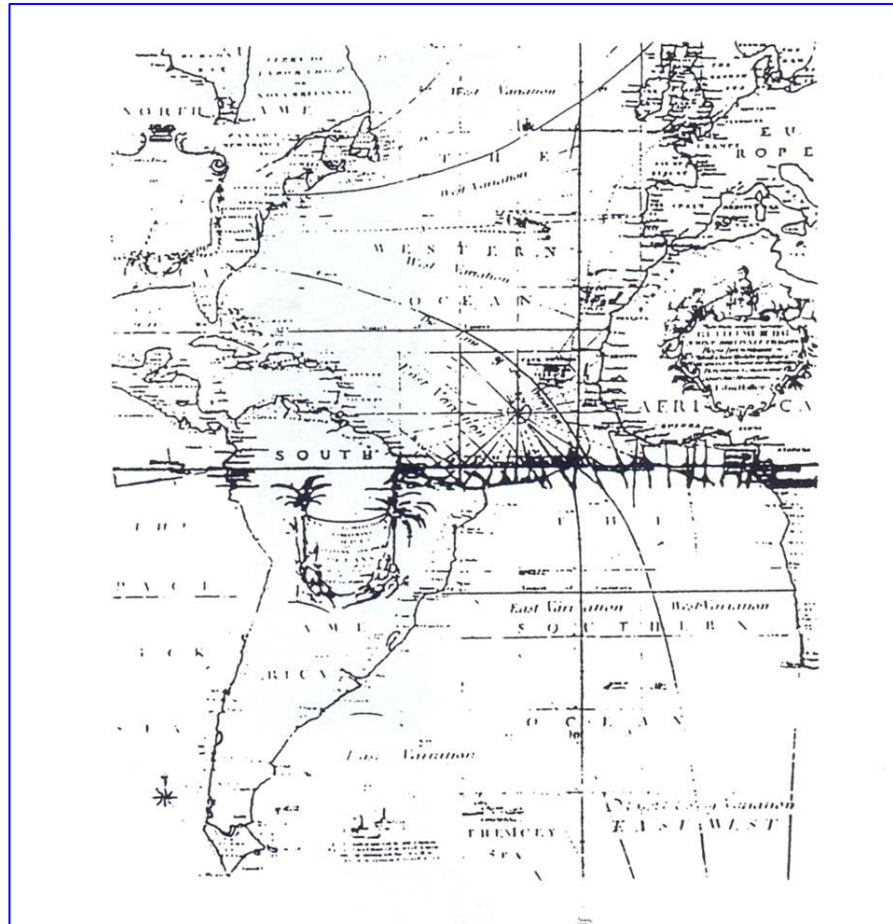
To analyze the ionospheric dynamo , it is necessary to select carefully the magnetic quiet days

Earth's Dynamo

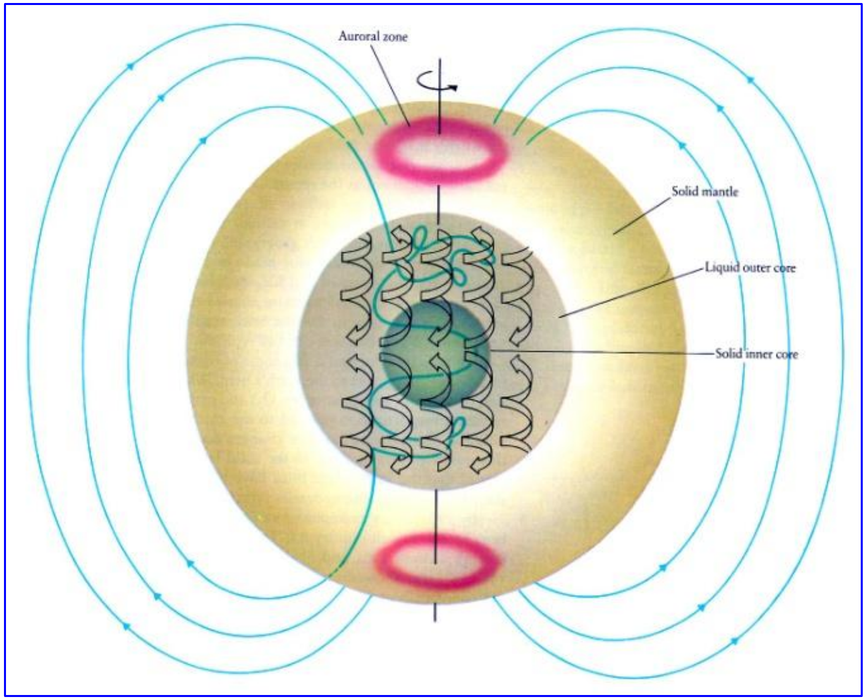
EARTH'S DYNAMO
Earth's magnetic field known since more 2 millenaries



Gilbert, 1600 -> Dipole



First map of the Earth's magnetic field Halley 1701



Internal Earth's dynamo -> Bp + Ba
Bp : main field , Ba : aimantaion field (Lithosphere)

Model of the terrestrial magnetic field IGRF
http://www.iugg.org/IAGA/iaga_pages/pubs_prods/igrf.htm

Dynamo	Motions – V	Magnetic field B	Order of Magnitude
Sun	Sun Rotation and convection	Sun : 2 components Dipolar Toroïdal = sunspot	rotation speed : ~ 7280km/h at the equator Dipolar component : ~10 G Toroidal component : ~3-5 kG
Solar wind Magnetosphere	Solar wind	Interplanetary medium -> Bi	speed ~ [400km/s to 1000km/s] Bi ~ qq 10 nT
Atmospheric wind Ionosphere	Atmosphere	Earth's -> Bt	speed ~ 100m/s Bt ~ qq 10 000 nT
Earth's Dynamo inside the Earth	Metallic core	Earth's -> Bt	Indirect measurements deduced from the Earth's planetary magnetic field and the secular variation Velocity ~ qq km/year Bt ~ qq 10 000 nT

This last dynamo is not considered for Space weather effects

Space weather project:
Solar Dynamo /Sun and solar events

- SUN
- NASA website and NGDC website
- www.spaceweather.com
- LASCO/SOHO Catalog

SOHO LASCO CME CATALOG

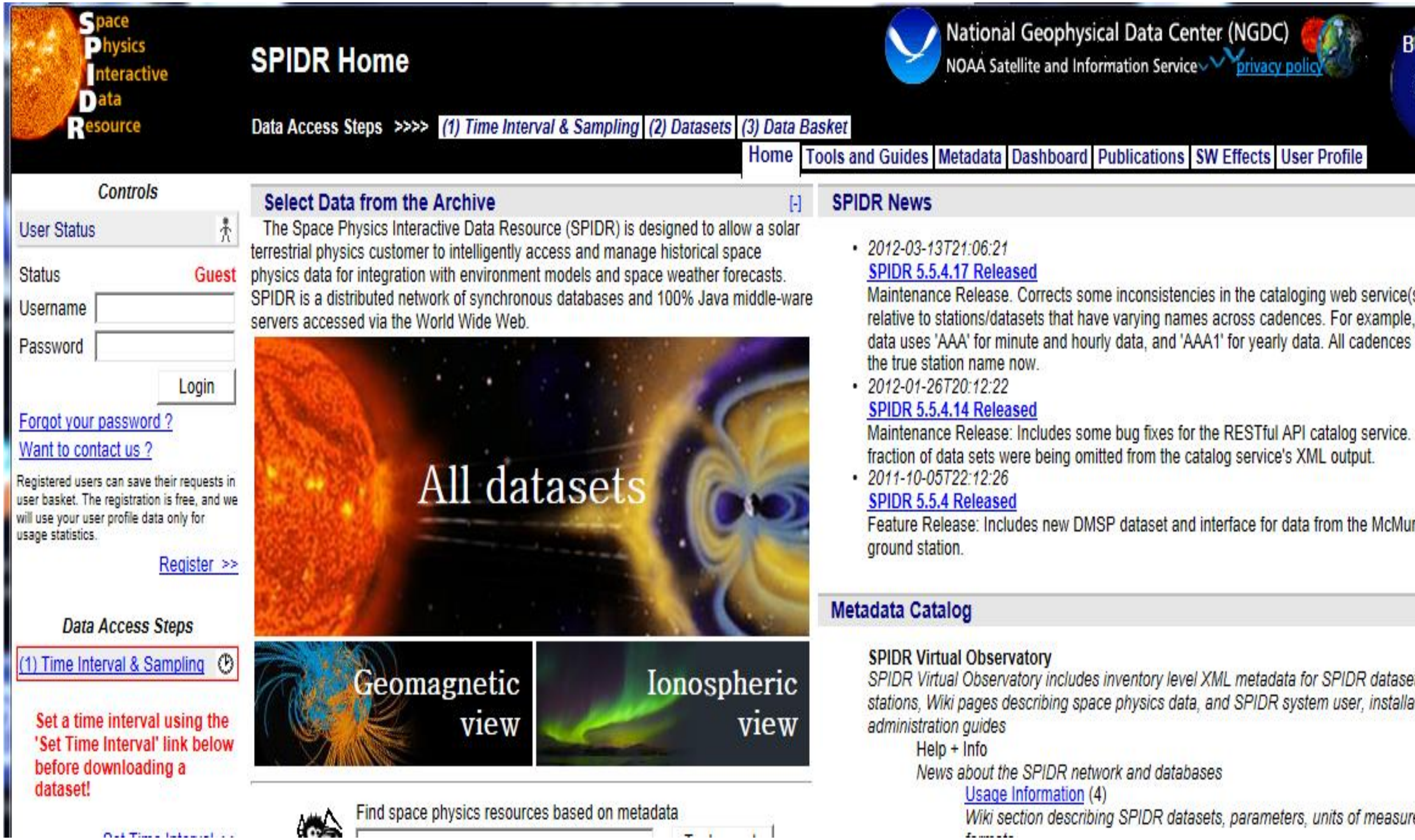
YEAR	MONTH											
1996	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1997	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1999	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2002	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2003	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2004	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2007	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2012	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2013	Jan											

Space weather project
Solar wind –magnetosphere dynamo

SPIDR data base

Use of the SPIDR -> Solar wind parameters

Space Physics Interactive Data Ressource



NECESSITY TO ANALYZE MANY PARAMETERS in order to understand the magnetic field, TEC etc… observations

- Sun
  - Sunspot cycle, poloidal cycle
  - Solar event
- Solar wind parameters V,B
  - Solar wind magnetosphere dynamo
- AU and AL
  - Auroral electrojets
- Dst -> [Hsym and H asym]
  - Ring current
- Ionospheric parameters
- Earth's magnetic field

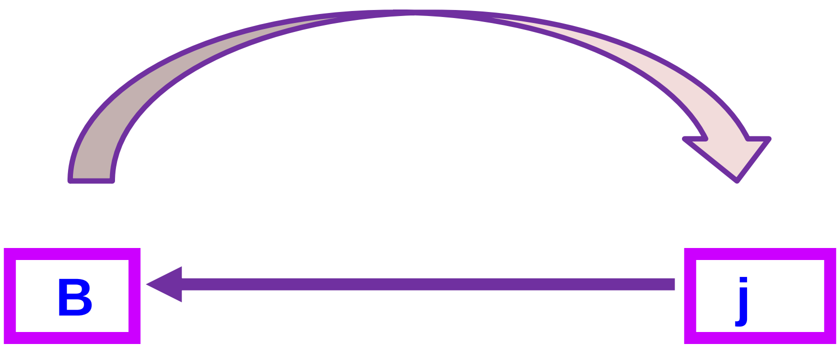
Electric current systems

Summary

- Space weather
  - Definition
- Sun Earth Links through dynamo processes
  - The main dynamo => Space Weather project
- Electric current systems associated to dynamo

There are very few measurements of electric currents and many measuments of magnetic fields

We will use the magnetic data to approach the electric currents



AMPERE 'S LAW

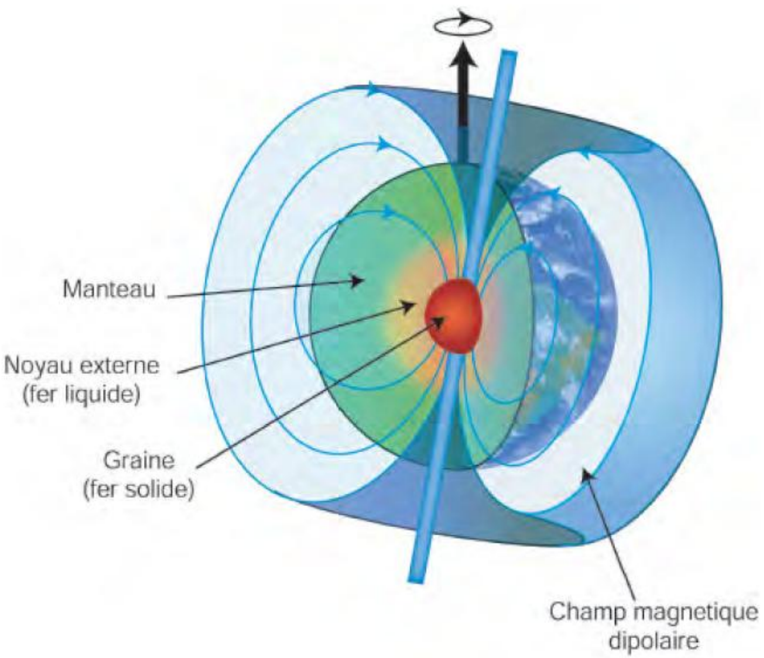
$\nabla \times B = \mu j$

OHM'S LAW

$j = \sigma (E + V \times B)$

- $B = Bp + Ba + Be + Bi$

Bp : Main field (core)
Ba : Aimantation field (Lithosphère)
Be : field related to external sources
Bi : induced by Be



Be : ionospheric and magnetospheric electric currents

The main field (Bp) changes very slowly : secular variation

The aimantation field is constant(Ba)

Transient variations of the Earth's magnetic field are due to external electric currents and are indirectly a measure of these currents

$$\Delta B = Be + Bi$$

$$\Delta B = S_R + D$$

Solar regular variation + Disturbance

$Sq = \langle S_R \rangle$ average of the variation of the quiet days

Electric current systems existing in the Earth's environment (Cole, 1966), Law Biot and Savart

$$D = DCF + DR + DT + DI + DG$$

DCF : magnetic

(~ qq nT to 30 nT)

DR : magnetic disturbance due to the ring current

<u>(~ qq nT to ~ 600nT)</u>

DT : magnetic disturbance due to the Tail currents

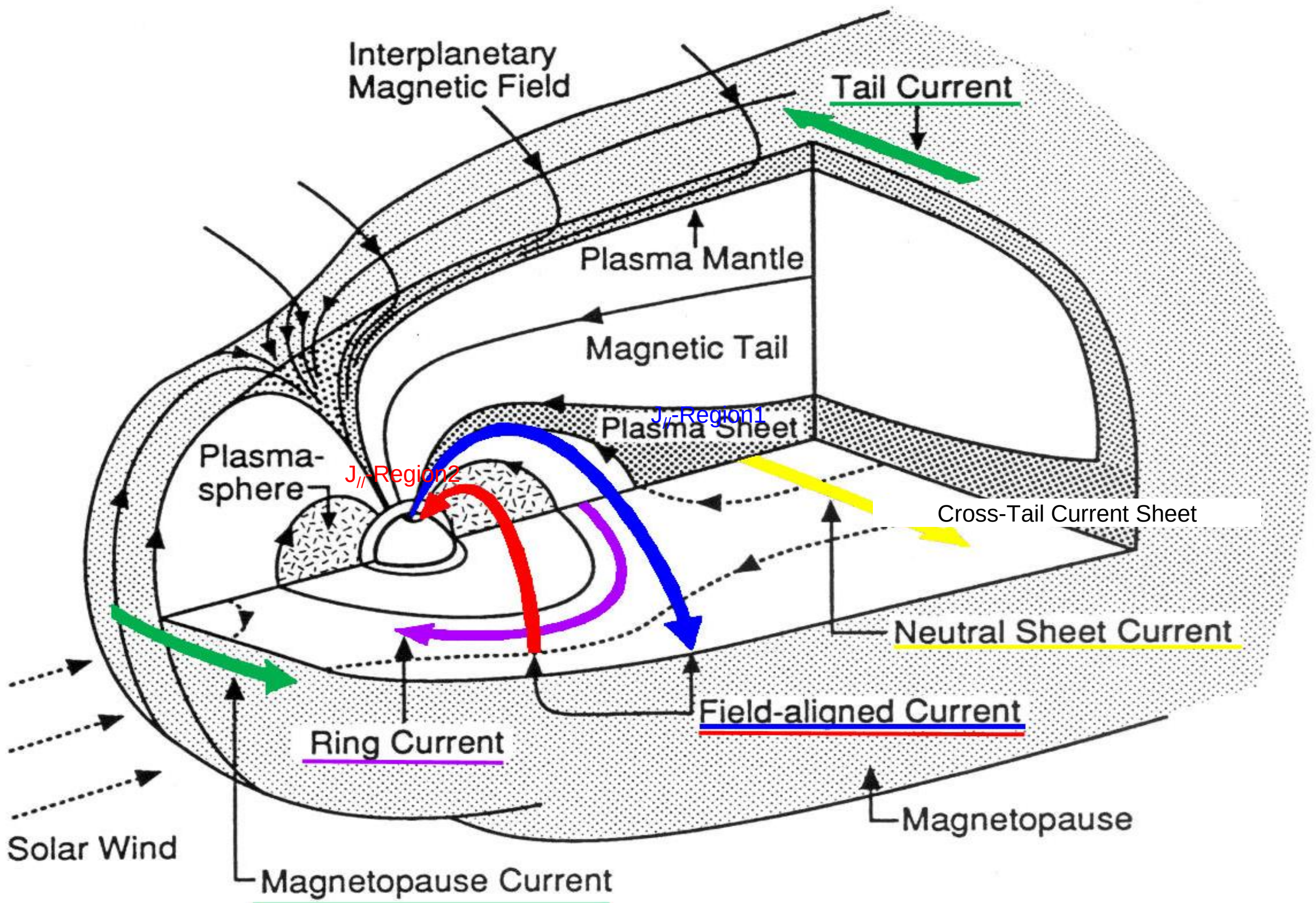
(~ qq nT to 20 nT)

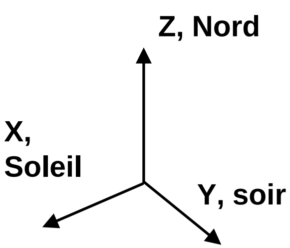
DI : magnetic disturbance due to the ionospheric disturbed electric current (DP0, DP1, DP2, DP3, DP4, Ddyn)

<u>(~qq nT to 2000 nT)</u>

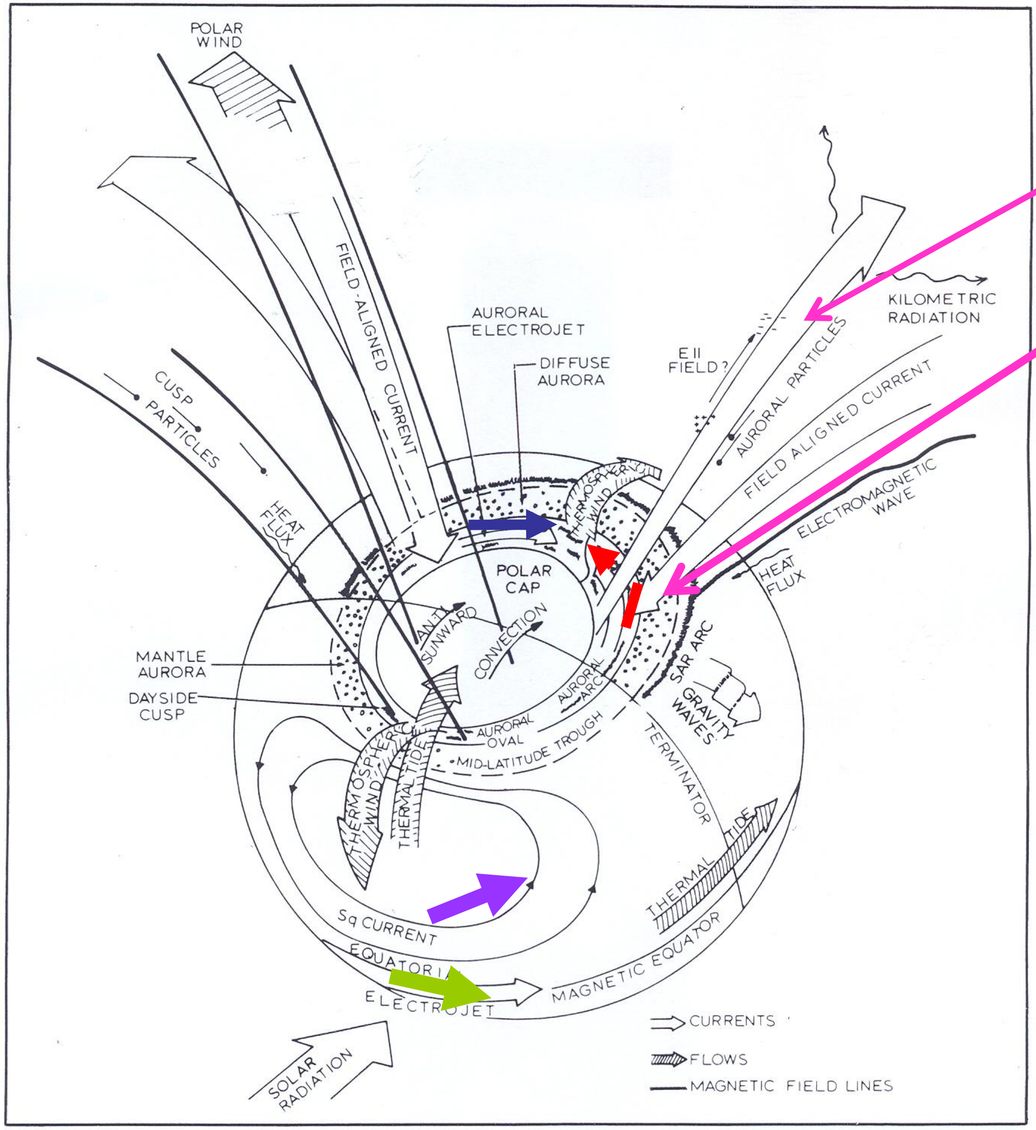
DG : magnetic disturbance due to electric currents flowing in the ground related to external electric current systems (~30 % or more) cause of power failure

Solar wind magnetosphere dynamo (Vs, Bi)
Electric currents in the magnetosphere





Ionospheric electric currents related to The SWM dynamo and Ionospheric dynamo



Field aligned current

Auroral electrojets

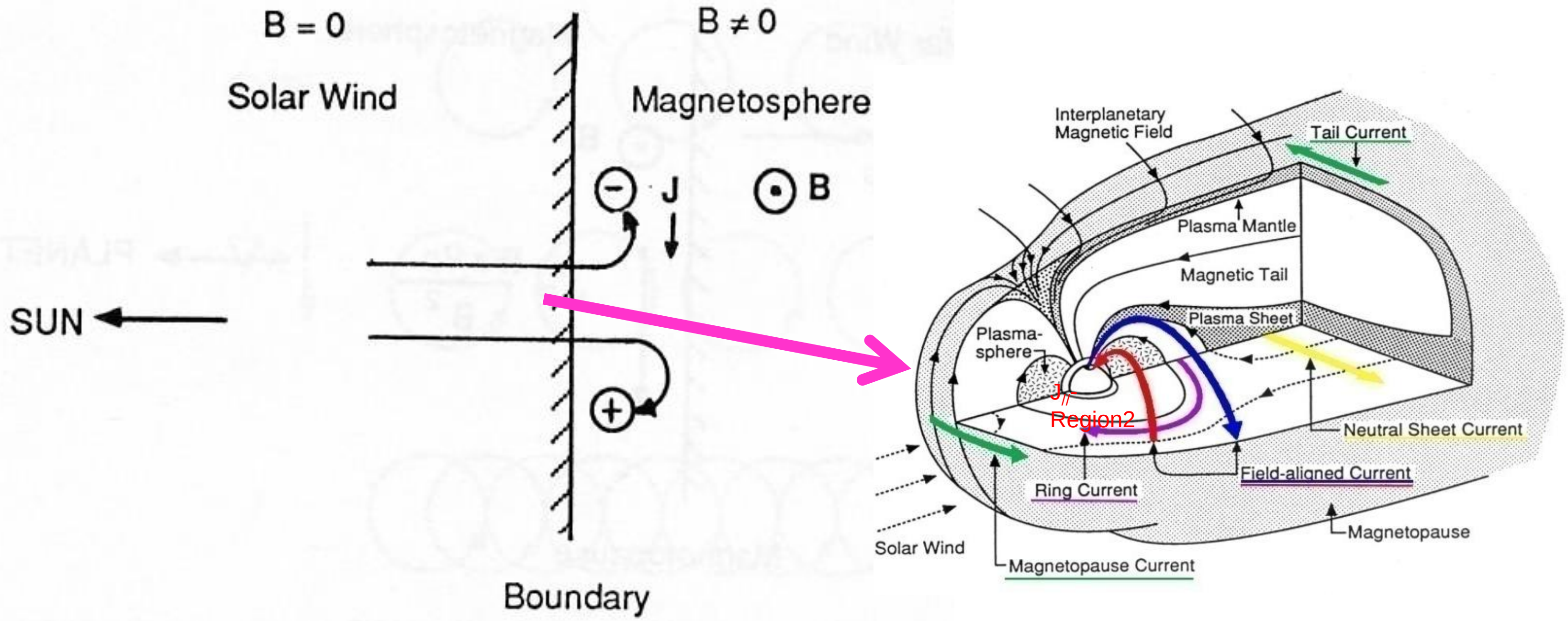
Precipitation of particles

Electric field

Auroral

Middle latitudes

Equatorial latitudes



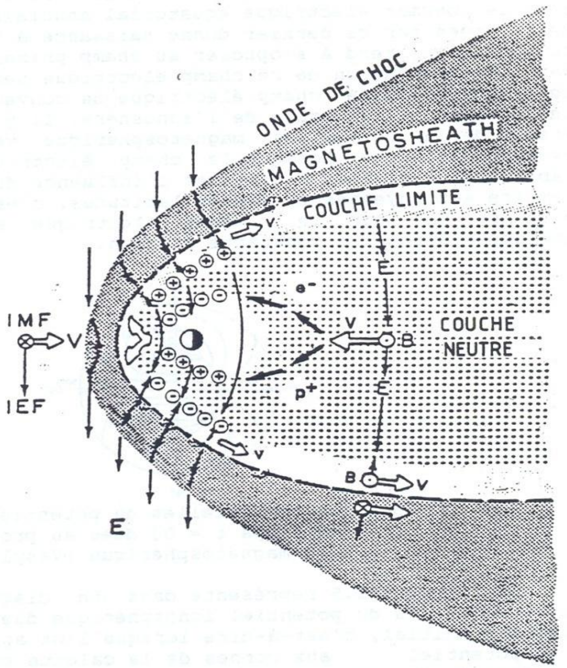
The Chapman Ferraro currents flow in the Magnetopause layer, the boundary between the solar wind and the geomagnetic field. At the nose of the magnetopause the geomagnetic field pressure is balanced by the dynamic pressure of the solar wind

$$K_1 N_i m_i V_i^2 = \frac{B_{mp}^2}{2\mu_0}$$

dynamic pressure of the solar wind ⇔ geomagnetic field pressure

K_1 is the correction factor for flow deflection in magnetosheath and compression of B. The order of magnitude of the Chapman Ferraro current is ~ 30 nT (Gosling et al. 1990).

Ring current



Dawn-dusk voltage drop difference

↓

Particles follow trajectories from the tail of the magnetosphere toward the Earth

↓

In the region where the curvature and gradient of the Earth's 's magnetic field are strong, particles are separated, the electrons are diverted to the morning side and the ions to the evening side.

Formation of the ring current

The expression of the drift due to gradient and curvature and the resulting current is:

$$\vec{V}_{gc} = \frac{1}{2} m V_{\perp}^{2} \frac{B \times \nabla B}{qB^{3}} + m V_{LL}^{2} \frac{B \times (b.\nabla)\hat{b}}{qB^{2}}$$

$$J_{gc} = NqV_{gc}^{ions}$$

This current is mainly carried by ions.

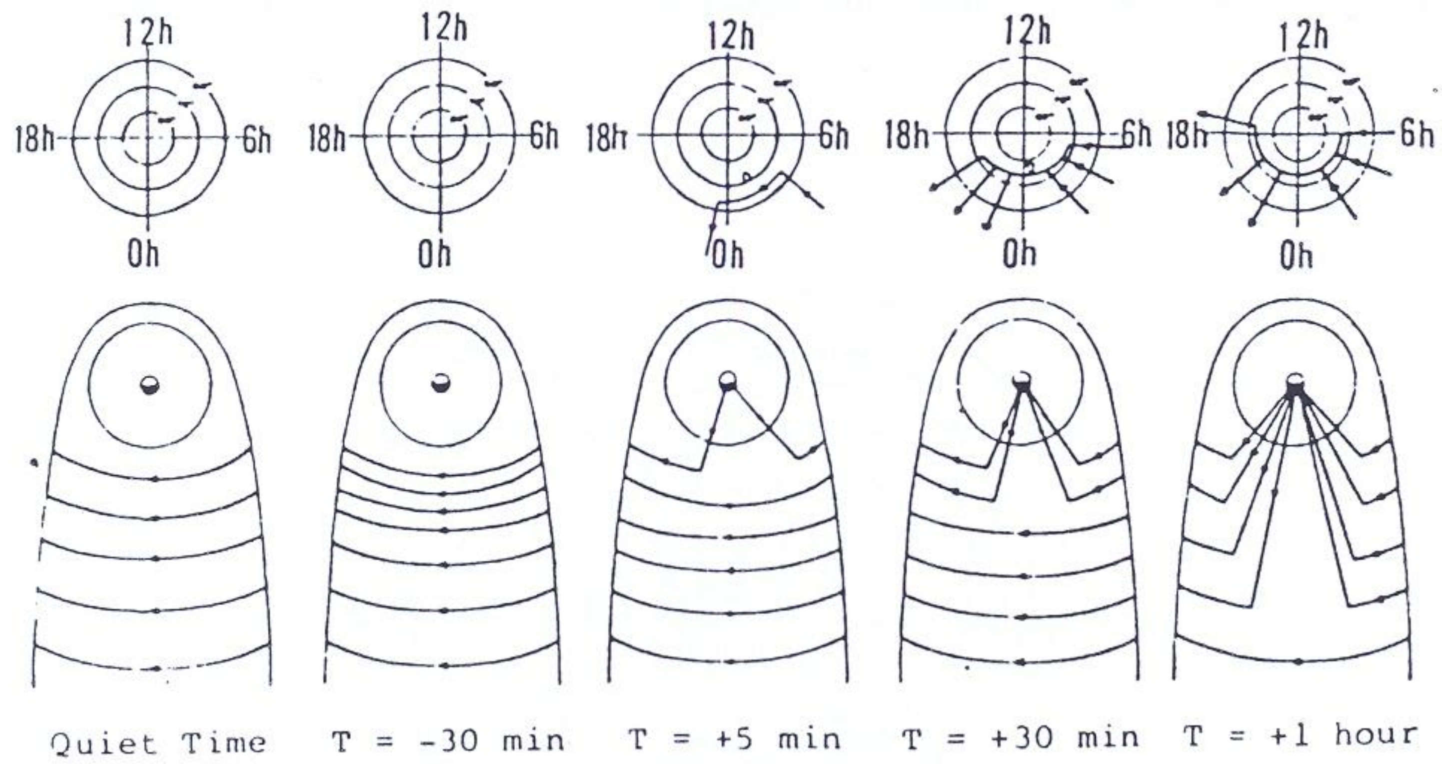
There is also an additional contribution of the magnetic moments of all particles:

$$\vec{M} = -N_i \frac{1}{2} \frac{m_i V_{i\perp}^{2}}{B} \hat{b} - N_e \frac{1}{2} \frac{m_e V_{e\perp}^{2}}{B} \hat{b}$$

$$\vec{J}_m = \nabla \times \vec{M}$$

The ring current keeps the pressure gradient and the Lorentz force in balance.

Tail currents / 1972



Proposed by Akasofu in 1972, the tail currents flowing at the boundary of the plasma sheet are disrupted and deflected toward the Earth on the evening side. These currents via Birkeland (field aligned current) be converted to a westward electrojet

Tail currents

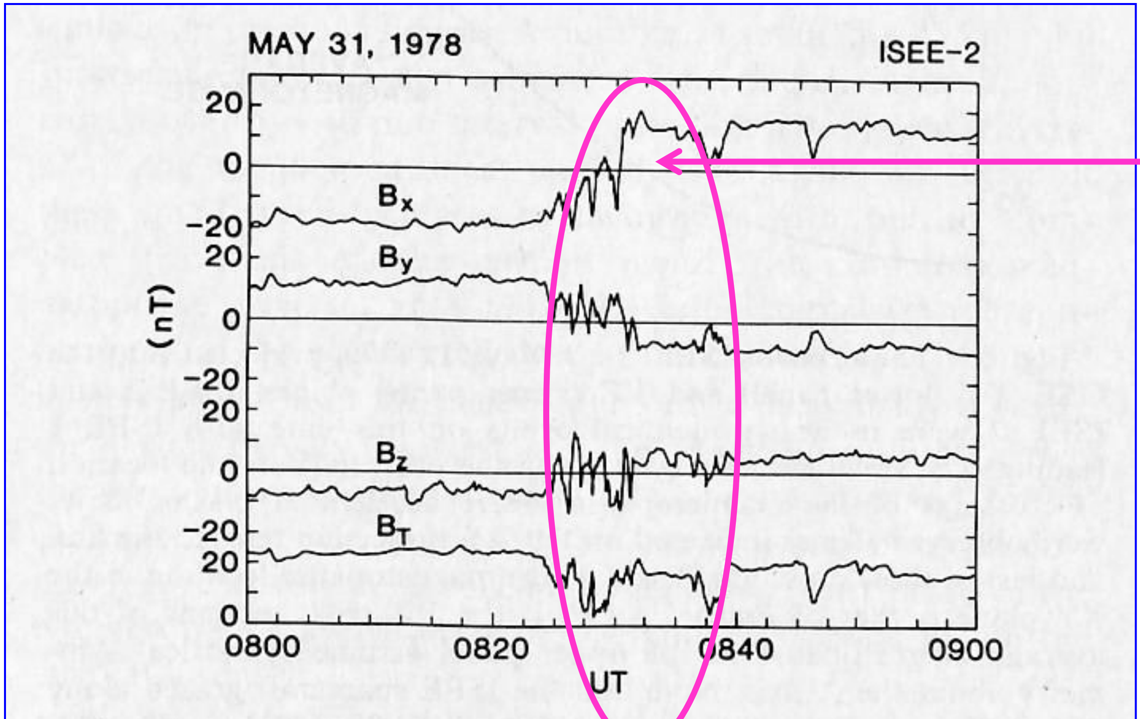
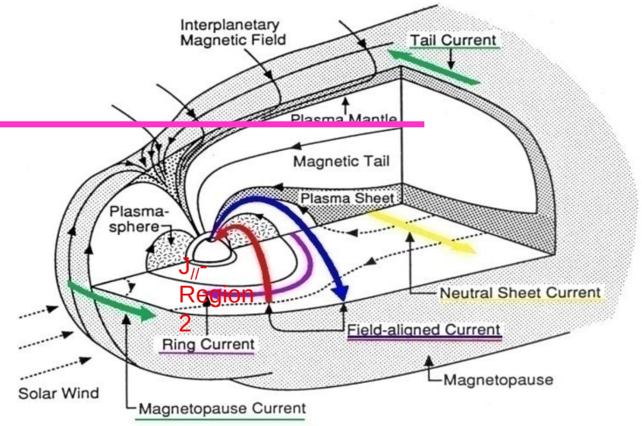
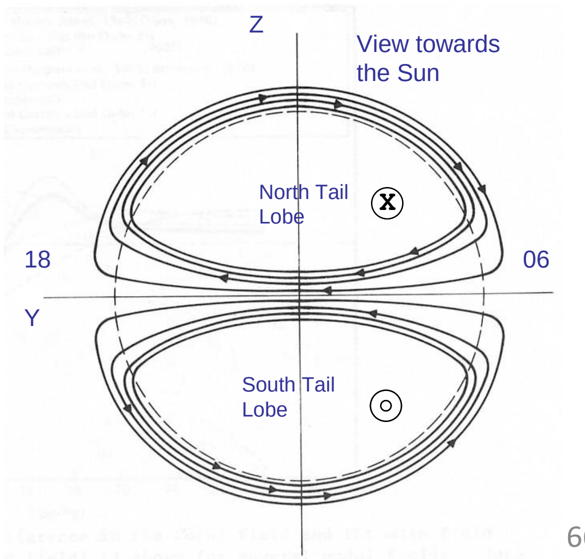


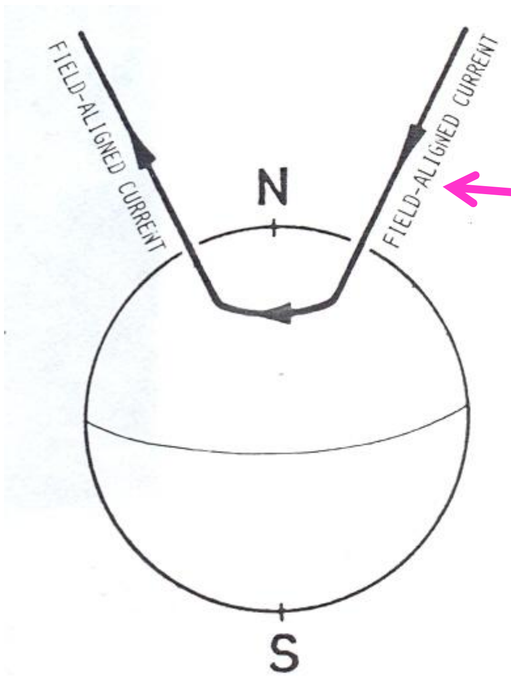
Fig. 2. Magnetic field data from ISEE 2 surrounding the ~0830 UT magnetopause crossing on May 31, 1978. From top to bottom the quantities plotted are the *x*, *y*, and *z* components (GSE coordinates) of the field and the total field magnitude.

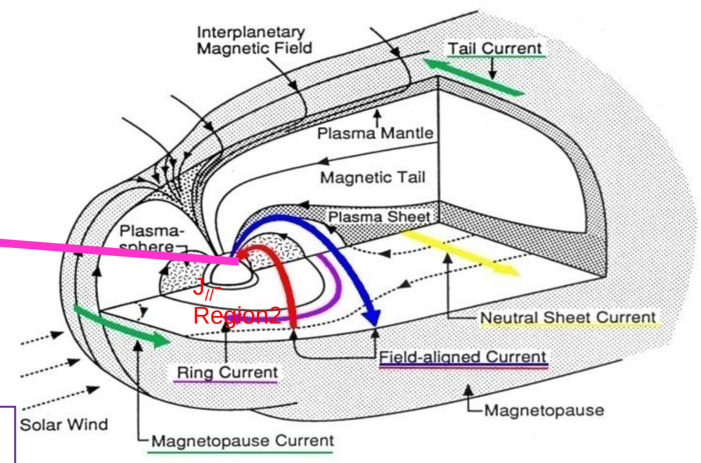




crossing of the magnetopause

Field aligned currents/1908





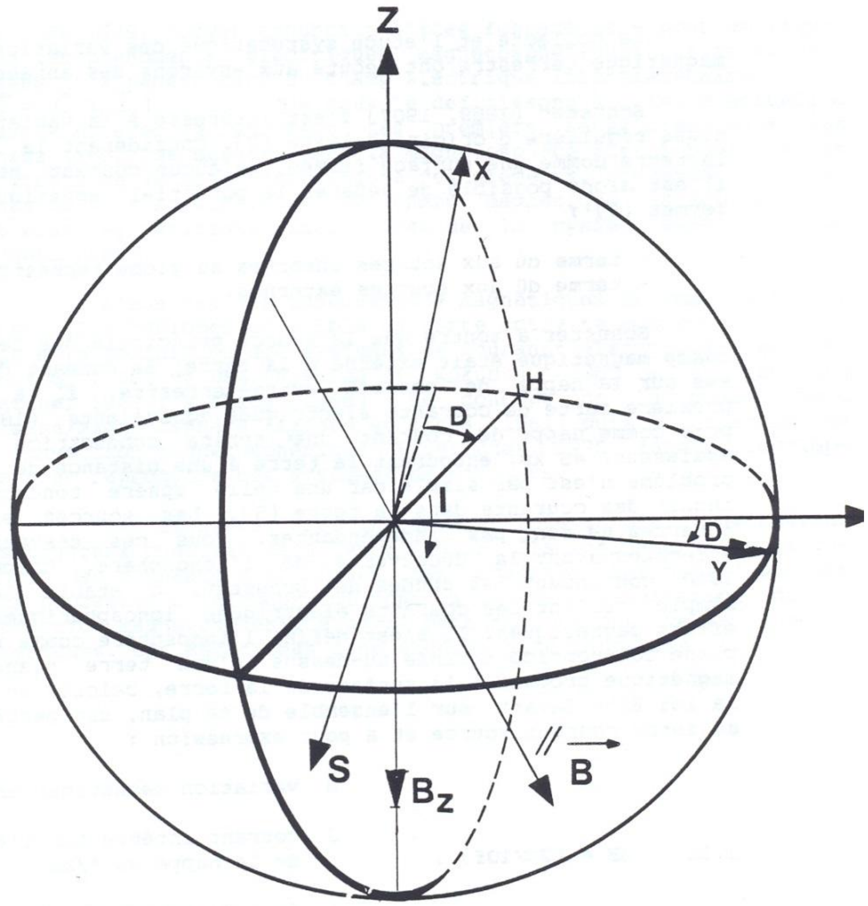
Birkeland, 1908

You can reproduce the experience of Birkeland

$$\nabla \vec{j} = \nabla_{\perp} \vec{j}_{\perp} + \nabla_{II} j_{II} = 0$$

The closure of the magnetospheric current loops requires field aligned currents flowing into and out of the ionosphere. The origin of the field aligned currents is near the equatorial edge of the magnetopause (region1), in the plasma sheet where the ring current is divergent (region 2) and at the magnetopause at high latitudes in the dayside.

THE EARTH MAGNETIC FIELD



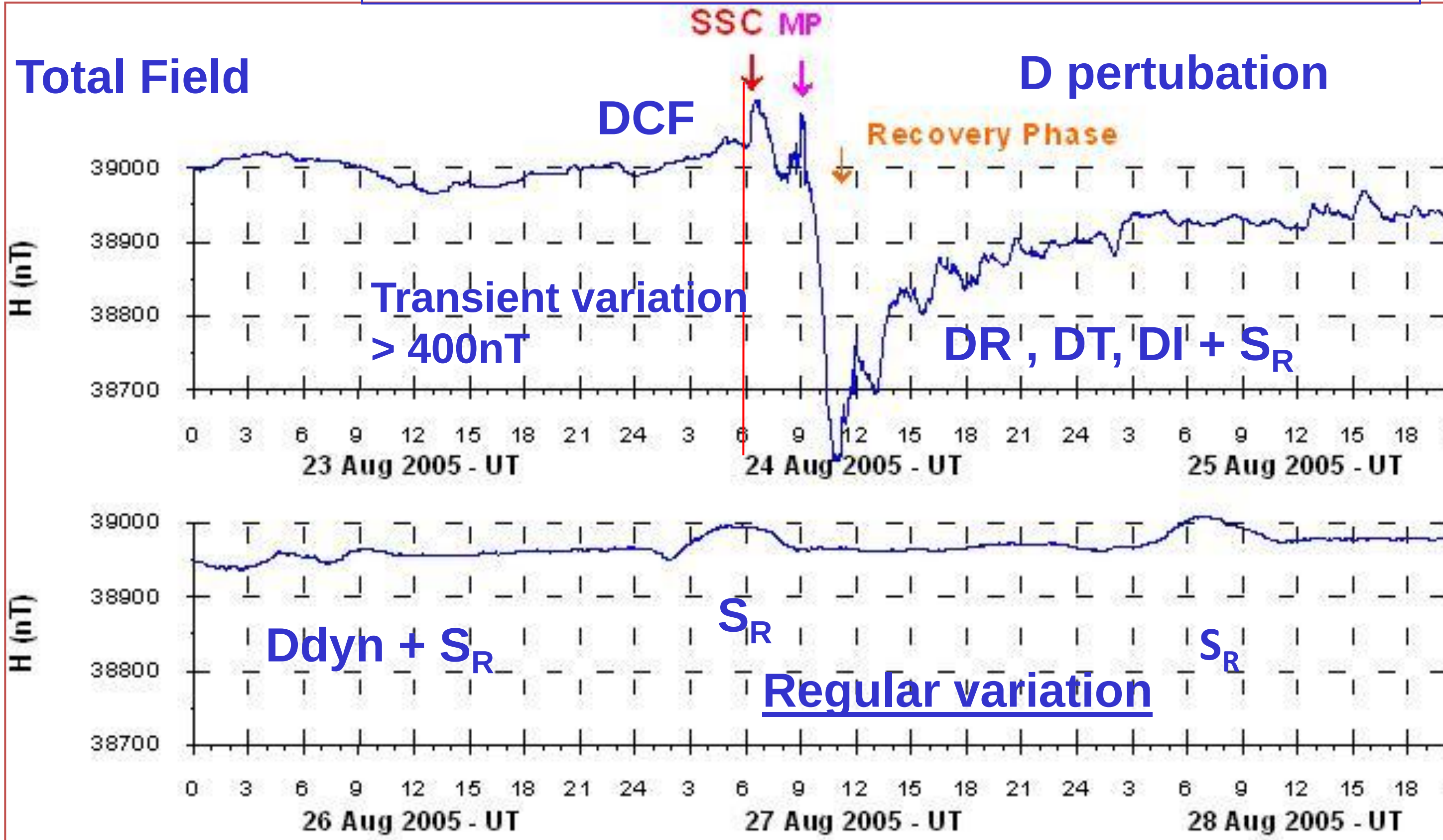
Components of the Earth Magnetic field

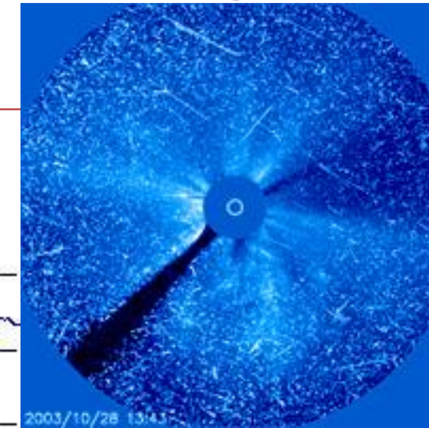
H : horizontal component
D : declination
Z: vertical component
I: inclination

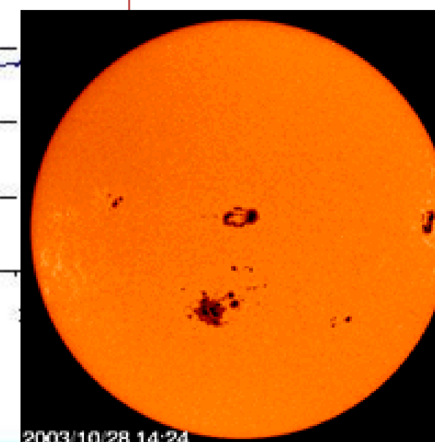
X : Northward component
Y: Eastward component
Z: Vertical component

earth’s magnetic field integrated the effects of all current systems

Day to day variability of the Earth magnetic field

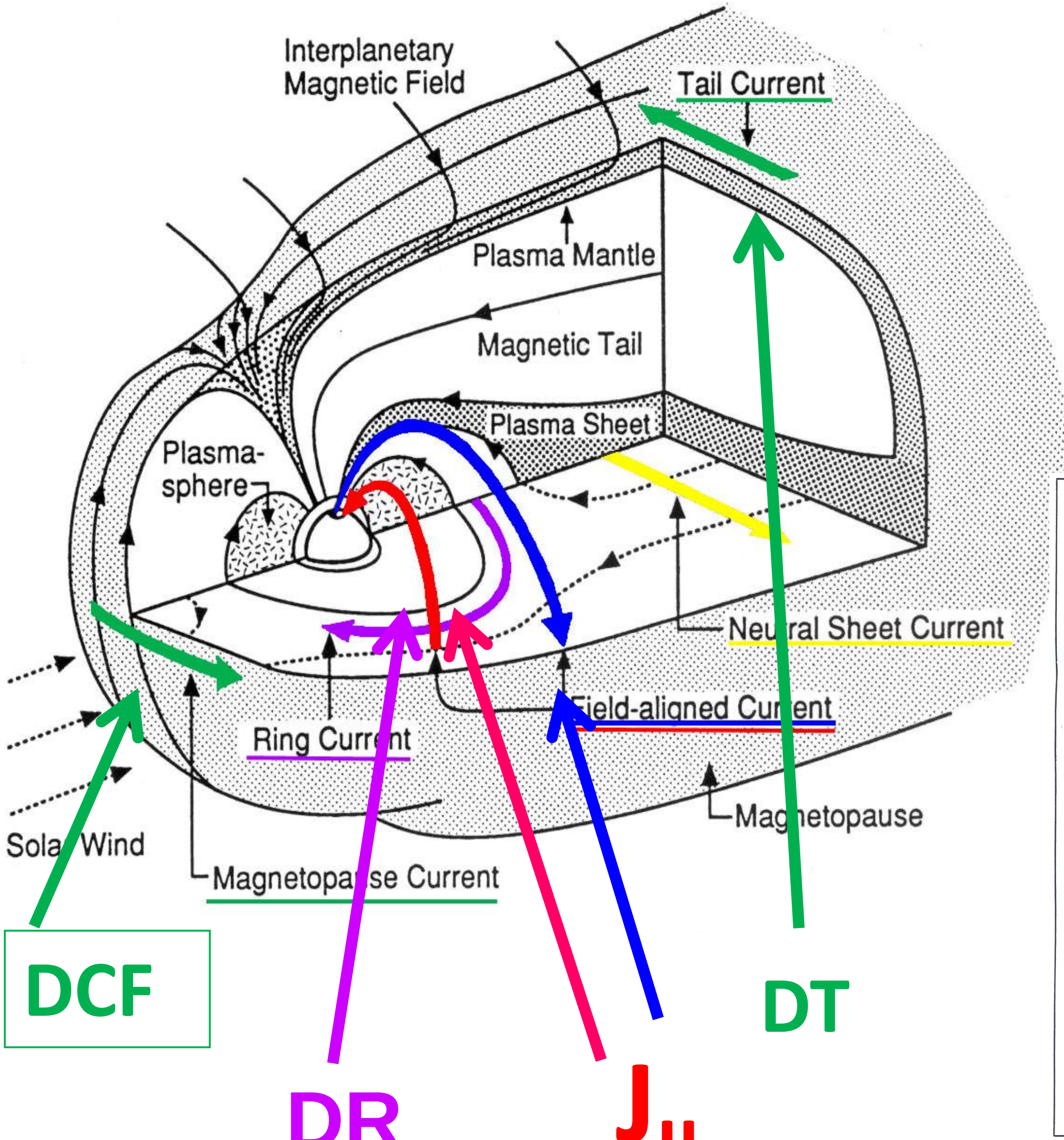




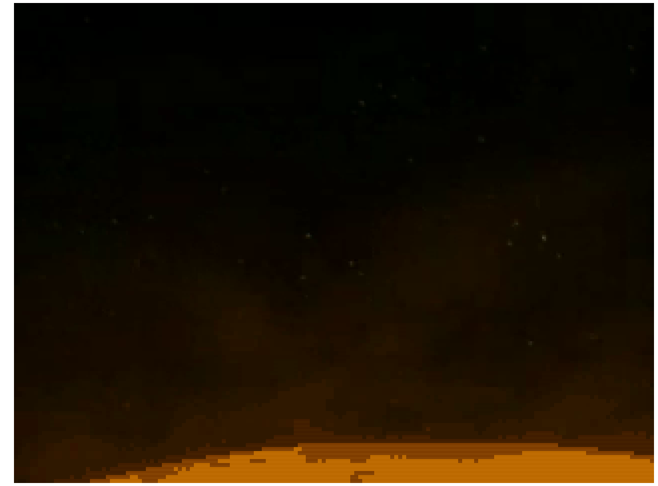


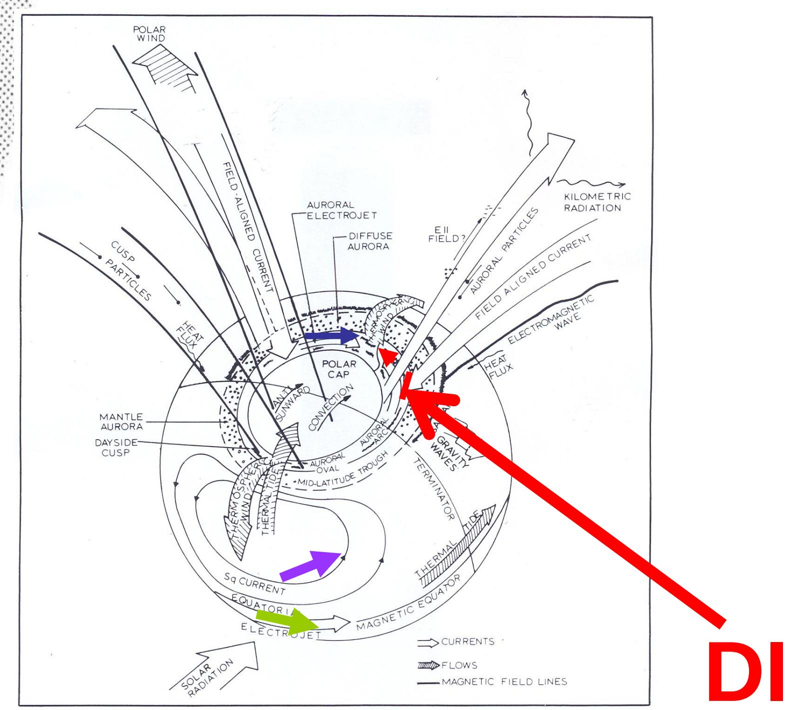
Time variation of the H-component observed at Phu Thuy (Hanoi – Vietnam) from 23th to 28th August 2005

Lat = 20N, long = 108E



Interplanetary Magnetic Field
Tail Current
Plasma Mantle
Magnetic Tail
Plasma Sheet
Plasma-sphere
Neutral Sheet Current
Field-aligned Current
Ring Current
Magnetopause
Solar Wind
Magnetopause Current
DCF
DR
$J_{\parallel}$
DT





POLAR WIND
FIELD-ALIGNED CURRENT
AURORAL ELECTROJET
DIFFUSE AURORA
KILOMETRIC RADIATION
AURORAL PARTICLES
FIELD ALIGNED CURRENT
ELECTROMAGNETIC WAVE
CUSP PARTICLES
HEAT FLUX
HEAT FLUX
POLAR CAP
CONVECTION
MANTLE AURORA
DAYSIDE CUSP
GRAVITY WAVES
TERMINATOR
AURORAL OVAL
MID-LATITUDE TROUGH
Sq CURRENT
EQUATORIAL ELECTROJET
MAGNETIC EQUATOR
SOLAR RADIATION
CURRENTS
FLOWS
MAGNETIC FIELD LINES
DI

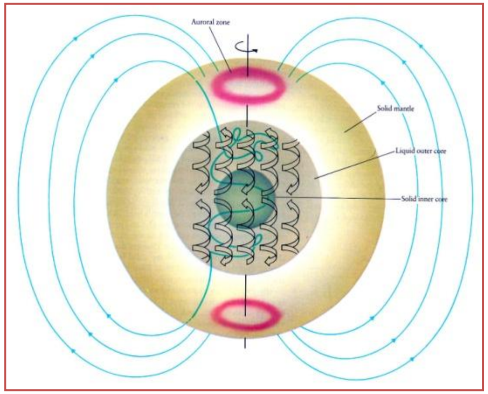
4 DYNAMOS IN

SUN
poloidal /toroidal

MAGNETOSPHERE
Solar wind
IMF

IONOSPHERE
Earth's magnetic field
Neutral wind

EARTH
Motions of the core

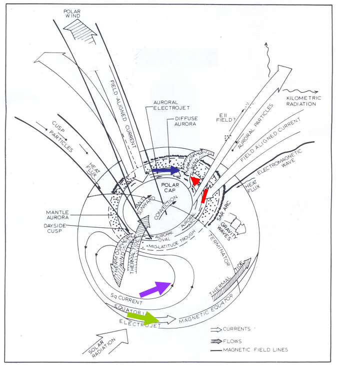


CURRENT SYSTEMS

MAGNETOSPHERE
Chapman Ferraro
Ring current
Tail current

FIELD ALIGNED

IONOSPHERE
Auroral electrojets
Midlatitude currents
Equatorial electrojet



EARTH's MAGNETIC FIELD -> Transient variations

Indices -> disturbances

Dst,

Aa, Kp, Ap

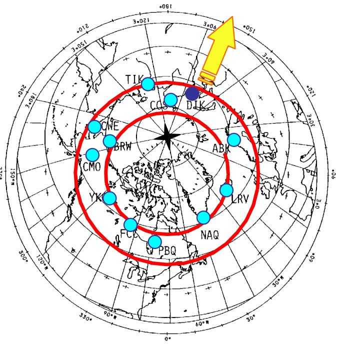
Km, Am

AU, AL

Equivalent currents

DP1, DP2,Ddyn

S_R <Sq>, Sq^P



- 2009 : Thèse d’Etat Frédéric Ouattara: Relation between the 2 components of the solar magnetic and Equatotrial Ionosphere
- Burkina Faso
- 2011: PhD of Hung Luu Viet on Telluric electric field in Vietnam
- 2012: PhD of Jean-Louis Zerbo on Solar activity, solar wind and geomagnetism Burkina Faso
- 2012: PhD of Hong thi thu Pham on regular ionospheric dynamo and long term variations in Vietnam
- 2014 : PhD of Alain Gnabhlou on long terme variations of ionosphere in West africa, Burkina Faso
- 2014: PhD of Christian Zoundi on the Variability of TEC in West Africa Burkina Faso

~ 20 papers

- List given to Prof S. Radicella