SPACE WEATHER

SCOSTEP School

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Summary

Earth's motions

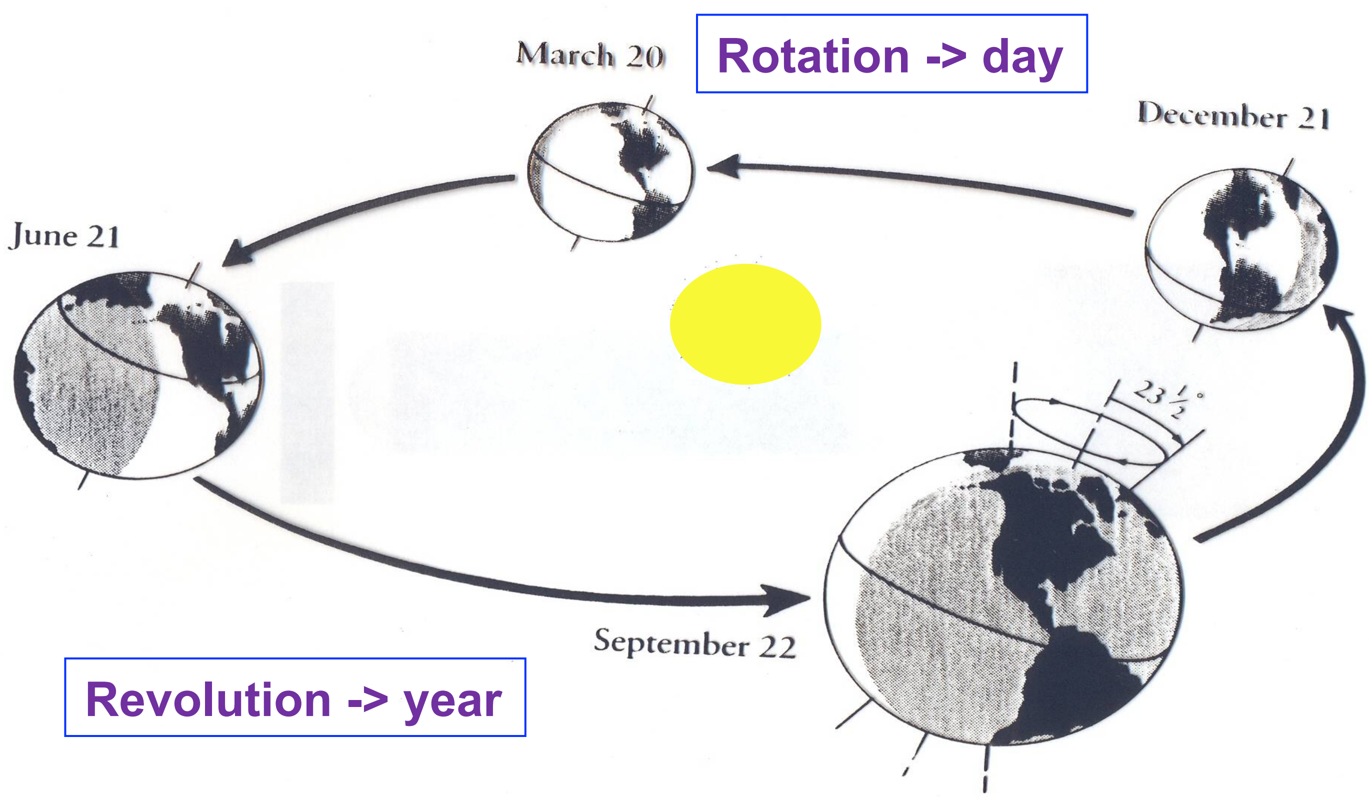
Definition of Space Weather

Sun Earth Links through dynamo processes : the main permanent dynamos

- Solar dynamo
- Solar wind/magnetosphere dynamo
- Ionospheric dynamo
- Earth's dynamo

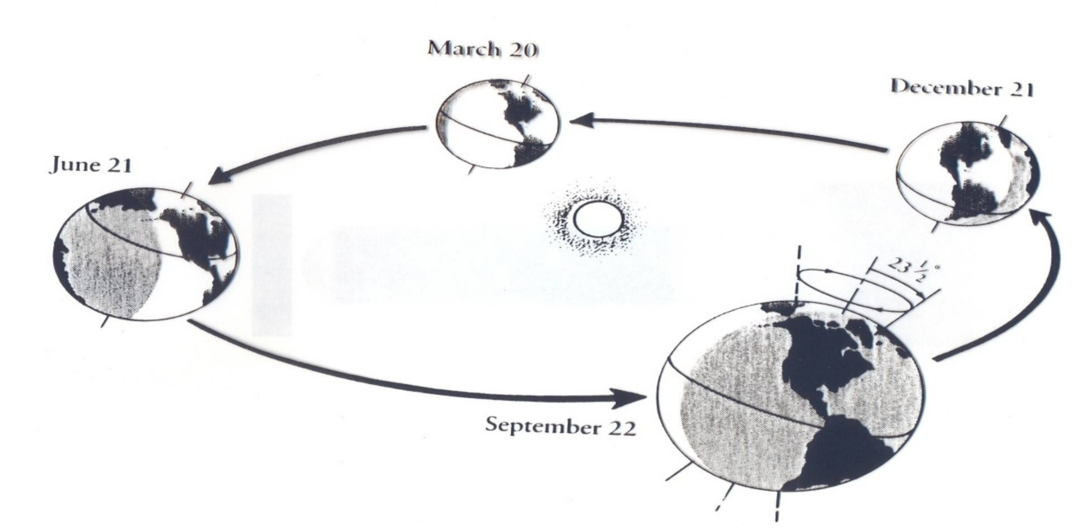
Electric current Systems

Motion of planets
Gravity force – Kepler 's laws

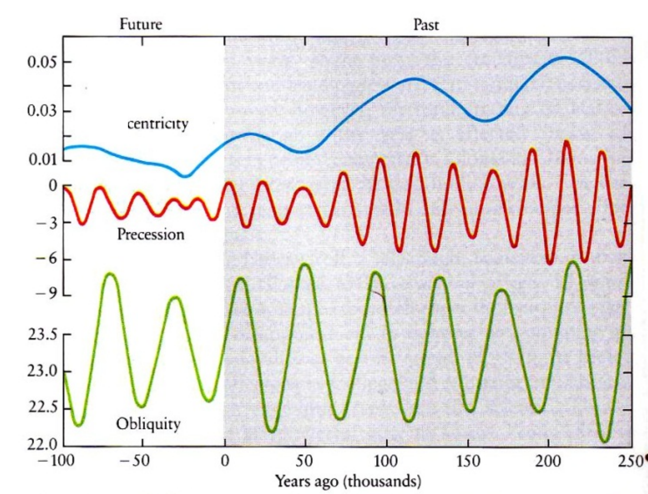


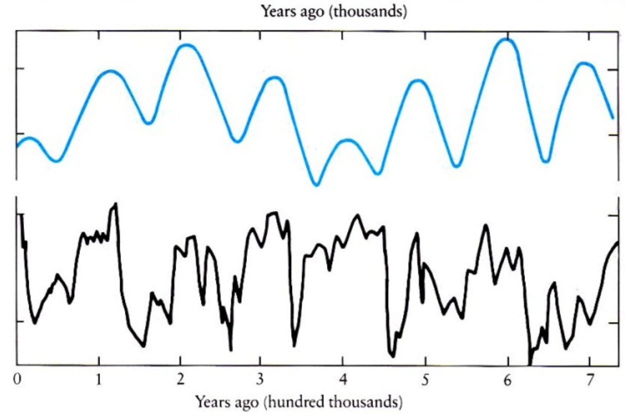
Diurnal variability -> rotation
Seasonal variability -> revolution

Motions of the Earth and Climate



Milankovitch 's theory
[1878-1958]
Three motions : precession, excentricity and obliquity explain the large periods of glaciation





Weather and Climate

Short and long time variations

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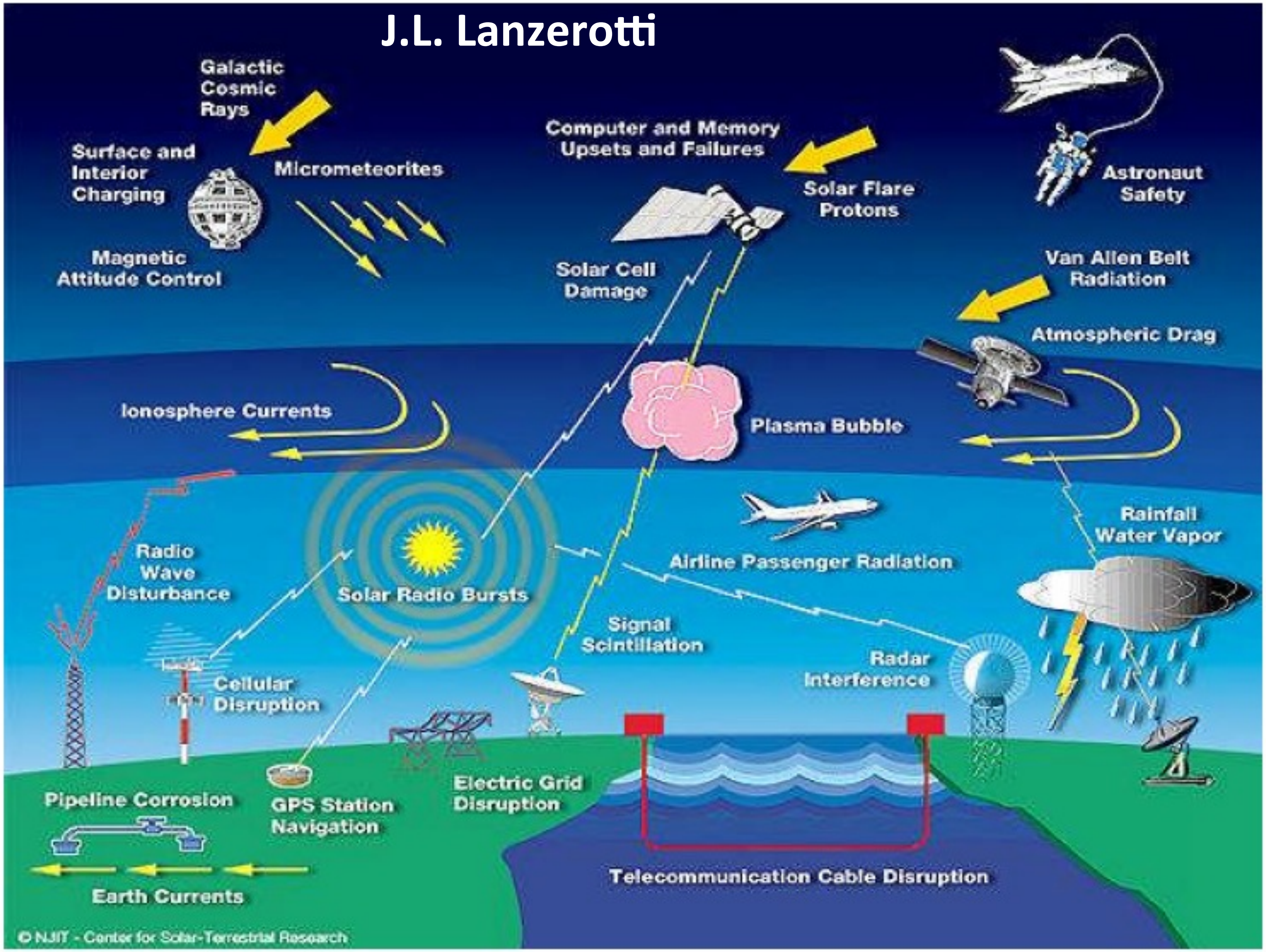
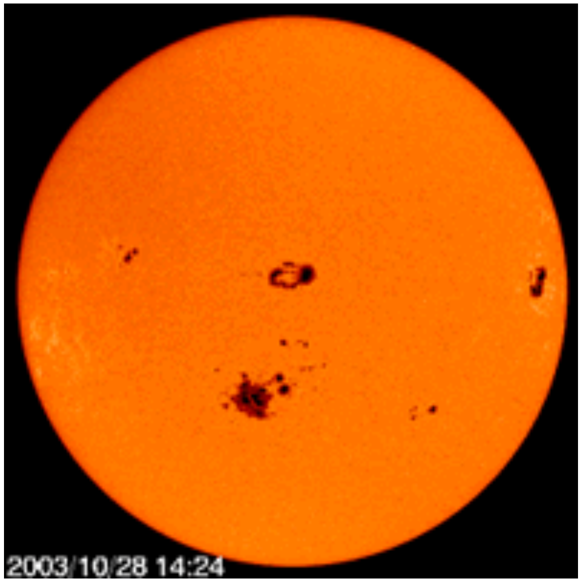
Electric current Systems

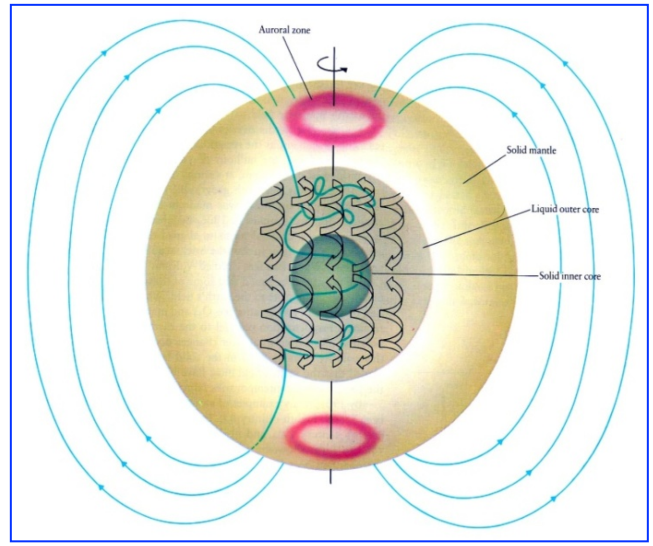
- **Space weather is the physical and phenomenological state of natural space environments. The associated discipline aims, through observation, monitoring, analysis and modelling, at understanding and predicting the state of the sun, the interplanetary and planetary environments, and the solar and non-solar driven perturbations that affect them; and also at forecasting and nowcasting the possible impacts on biological and technological systems**

SPACE WEATHER (technological systems)





Sun and Earth are 2 magnetized bodies in motion



Dynamo Processes in the Sun Earth System

↓

Systemic analysis of the Sun Earth system

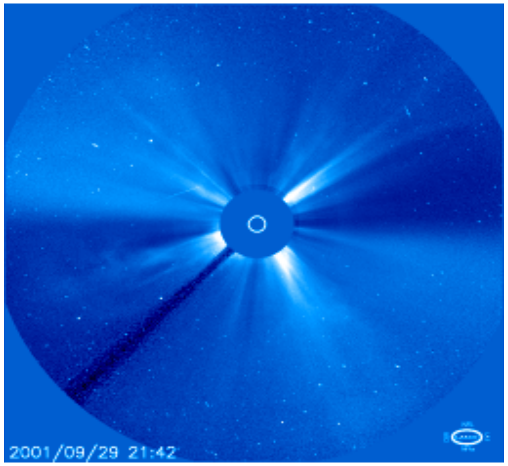
SPACE WEATHER (physical approach)
Links between Sun and Earth

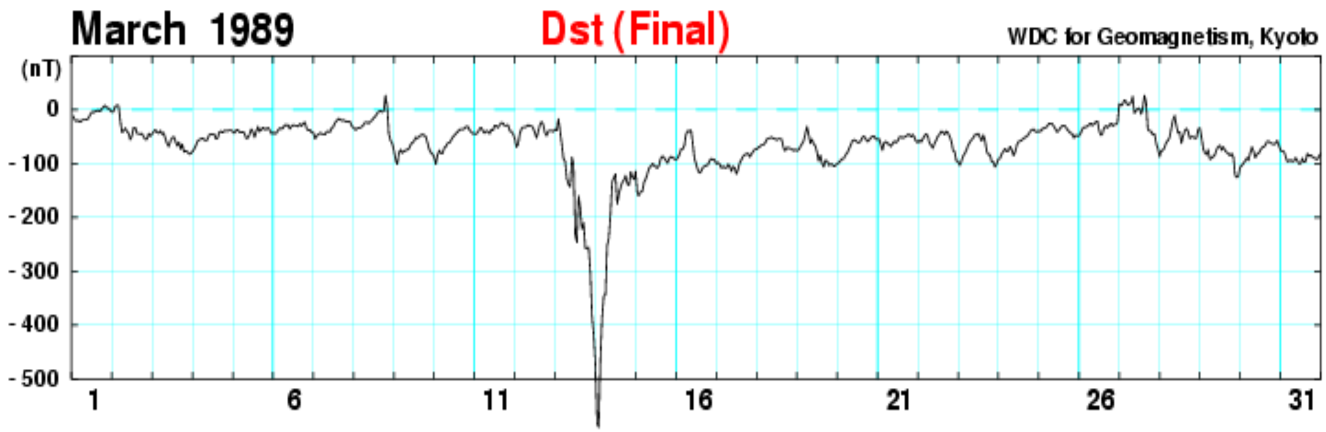
Prevision of all the effects of a CME on the Earth and on technologies
A work for the next decades

Movie of NASA

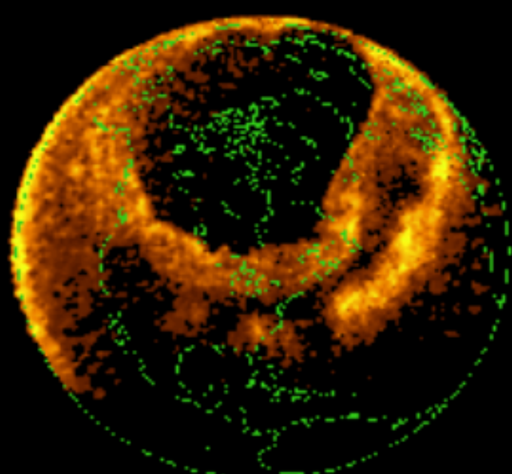
MAGNETIC STORM OF MARCH 15, 1989

the auroral oval extends toward low latitudes





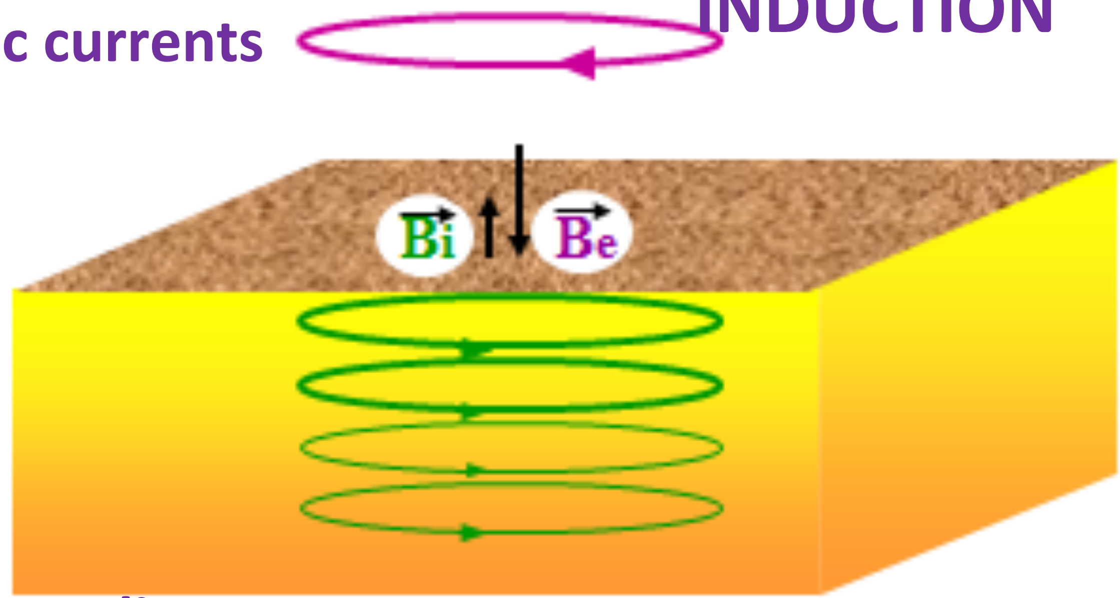
Power failure



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



GIC : Ground Induced Current => power failure

Space weather implies the knowledge of the complex Sun Earth System

many disciplines are concerned

Solar physics

Studies on solar wind

Magnetospheric physics

Ionospheric studies

Atmospheric physics

Geomagnetism

Magnetotelluric studies Geology

Global Navigation Satellite System

Etc…

Necessity to break walls between disciplines

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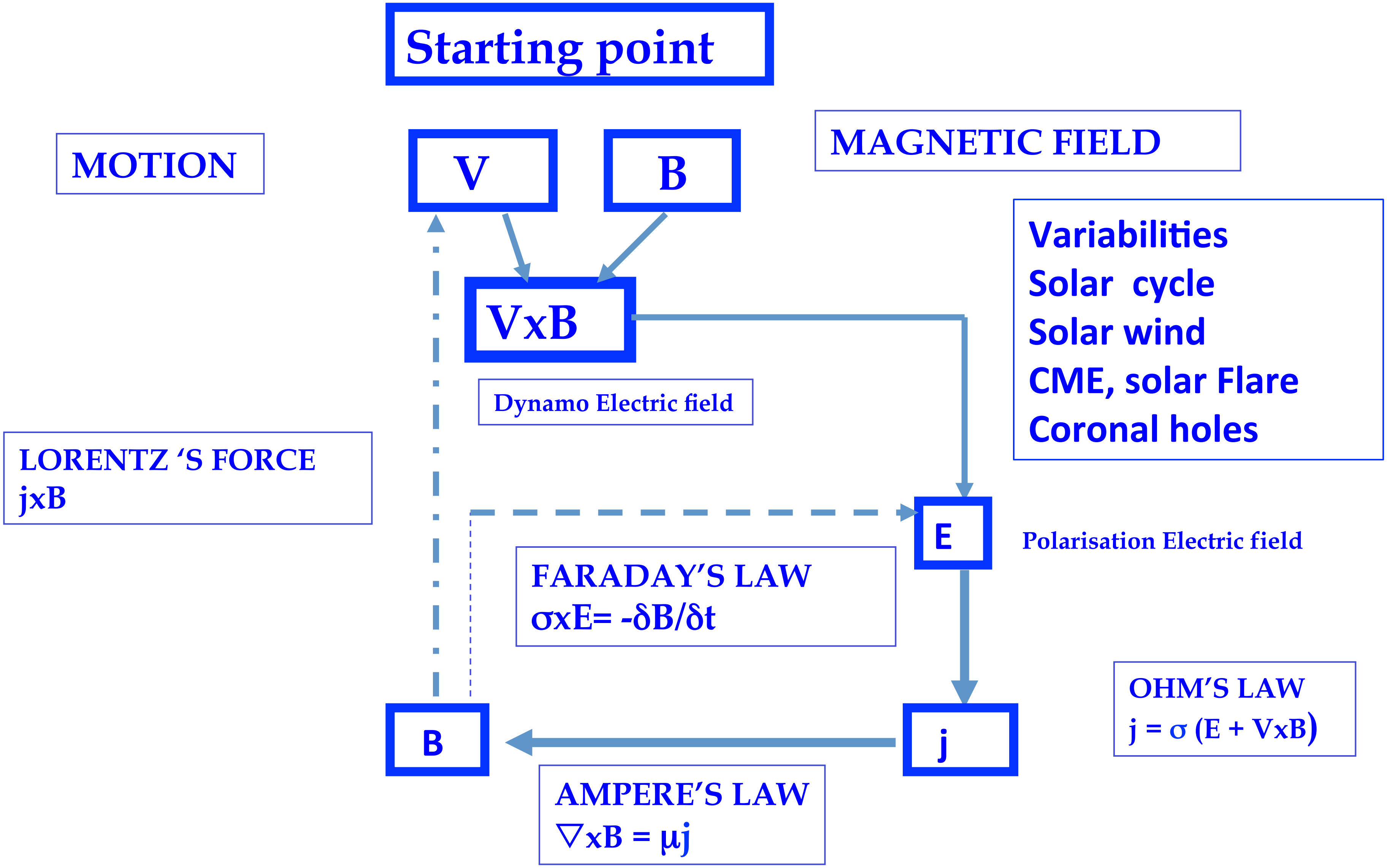
Electric current Systems

14

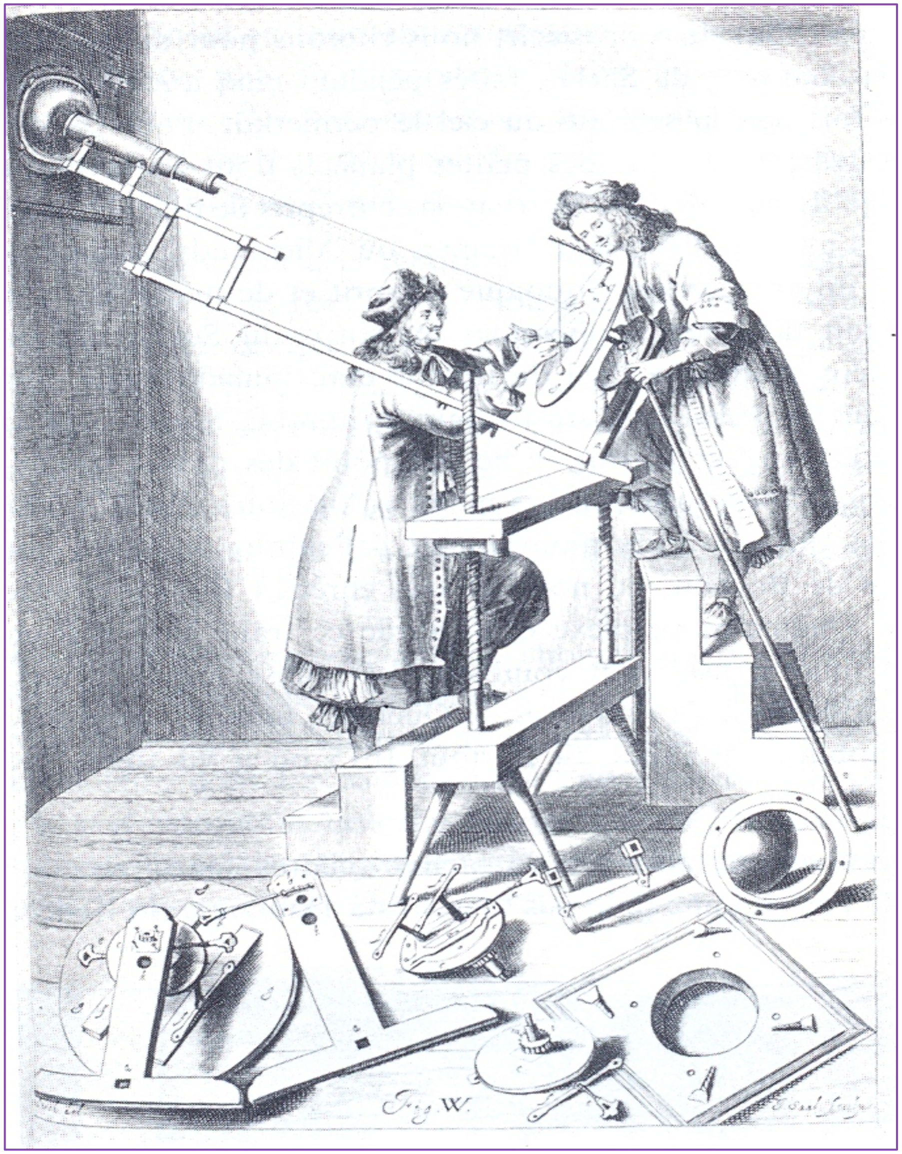


Principle of the DYNAMO ACTION

SOLAR DYNAMO

Mark Miesch

Observation of the Sun : Sunspots

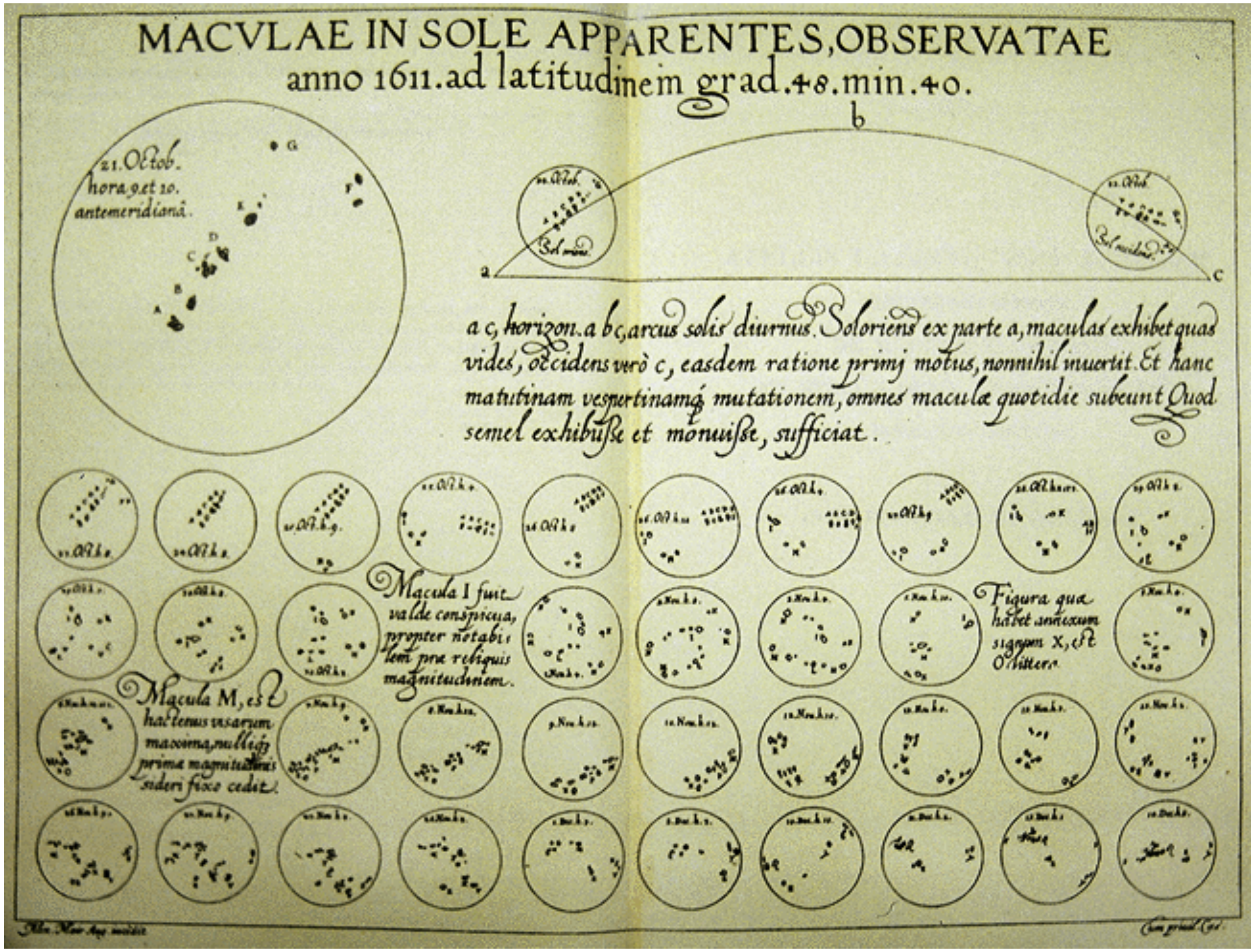


Hévélius
1642- 1644

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

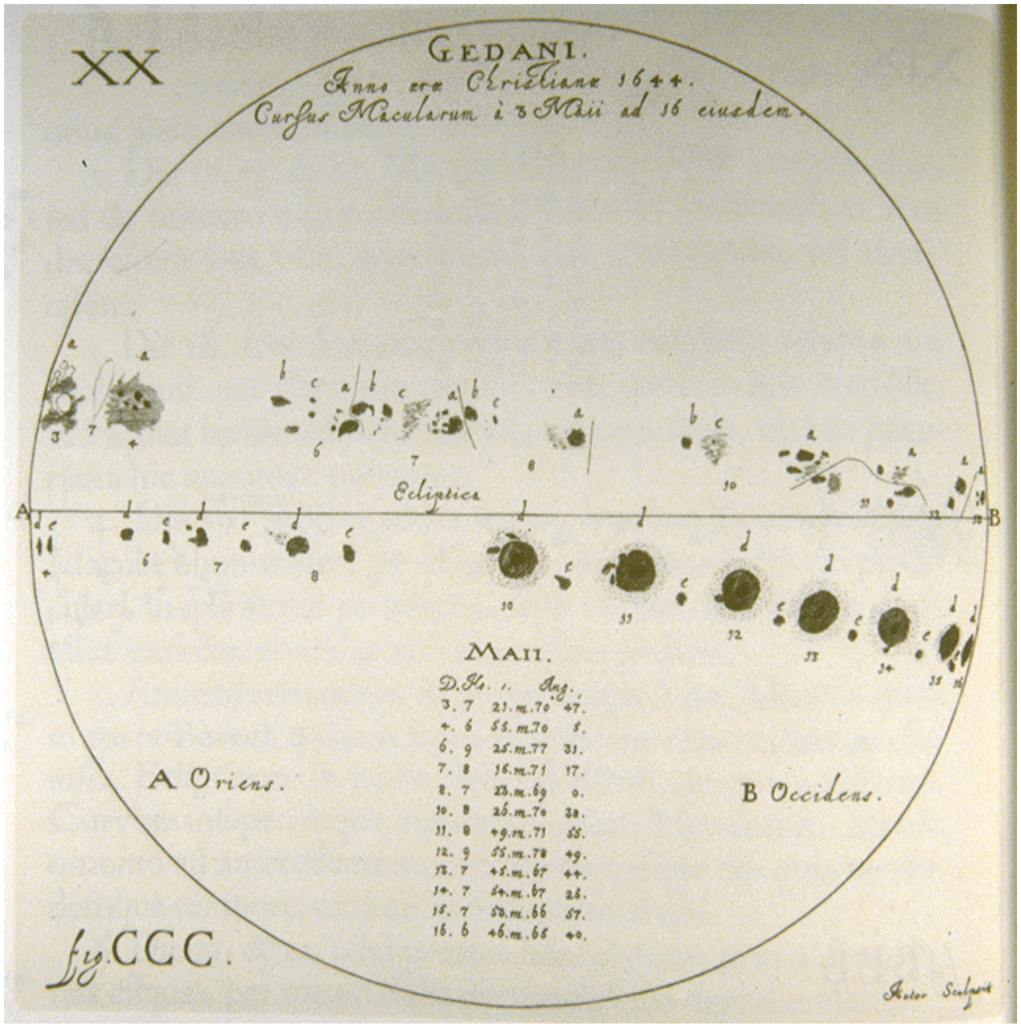
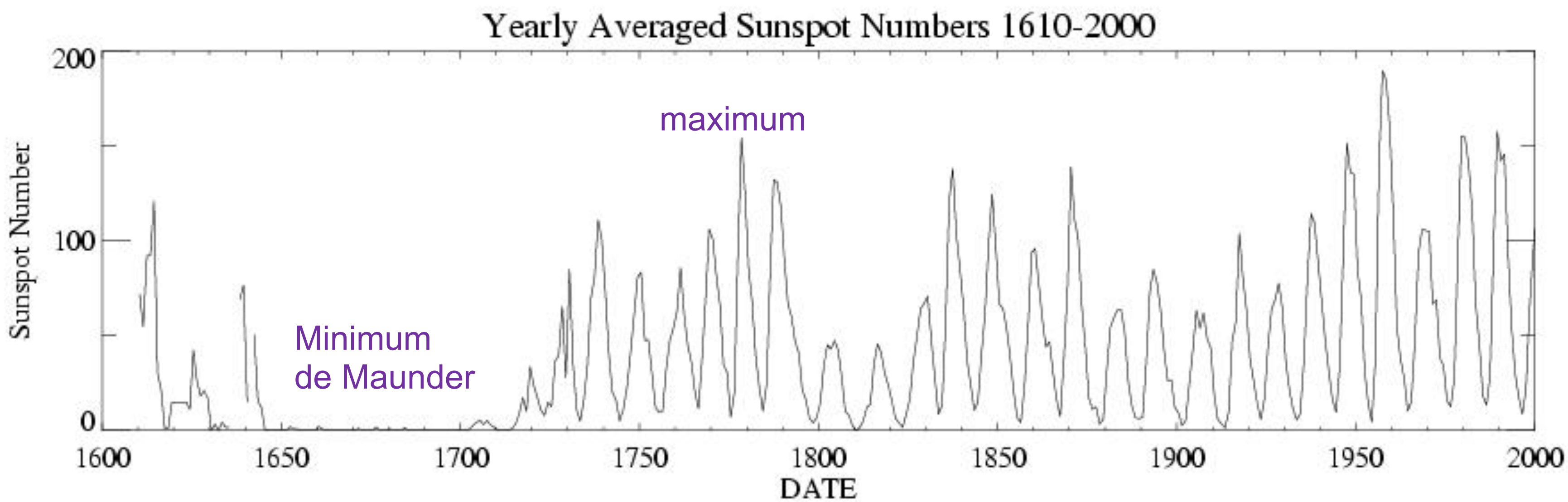


Figure of Father Scheiner
Motion of the sunspots

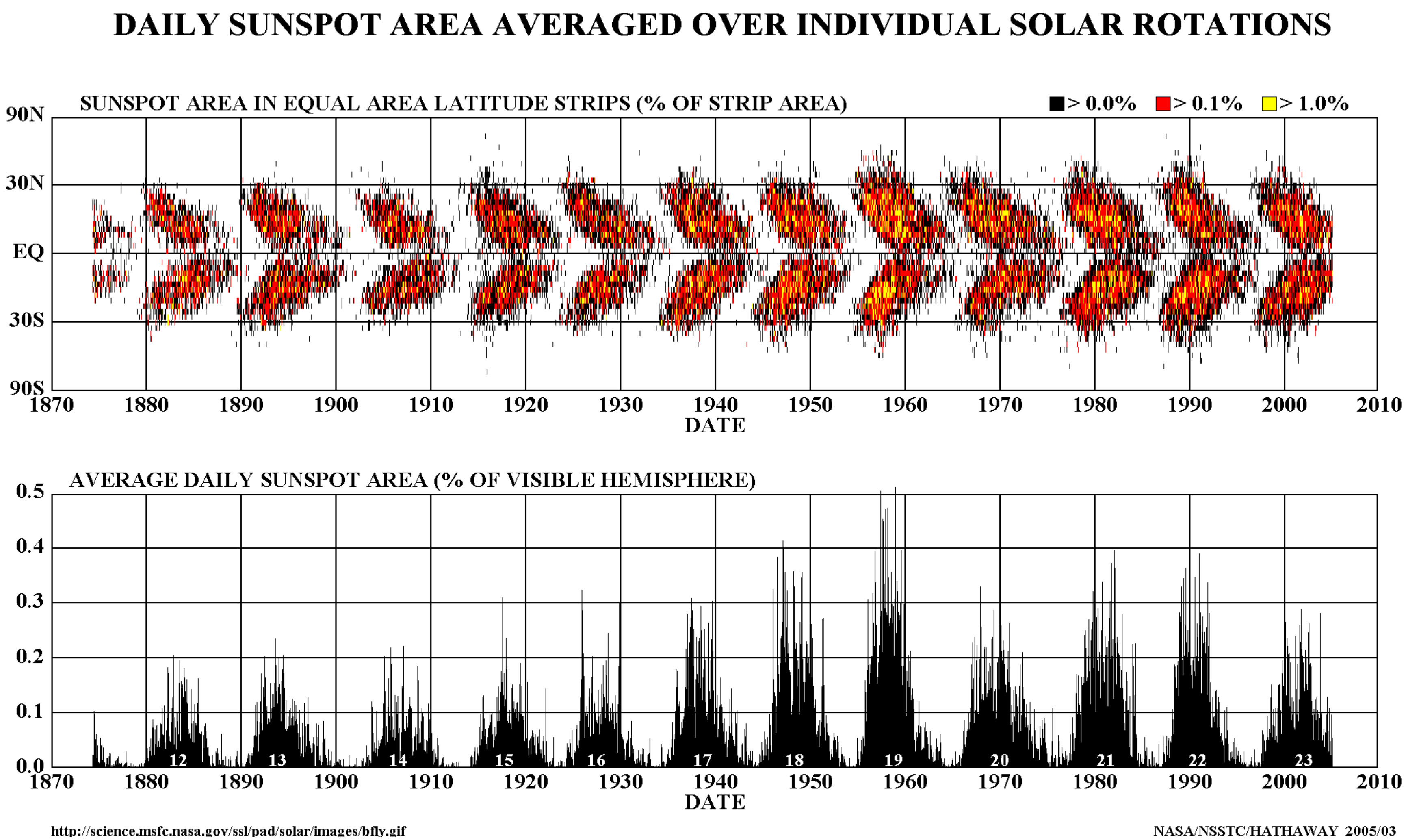
Scheiner : Priest Jesuit mathematician working at the university of Ingolstadt (near Augsburg)

Solar Cycle of 11 years : Heinrich Schwabe 1859

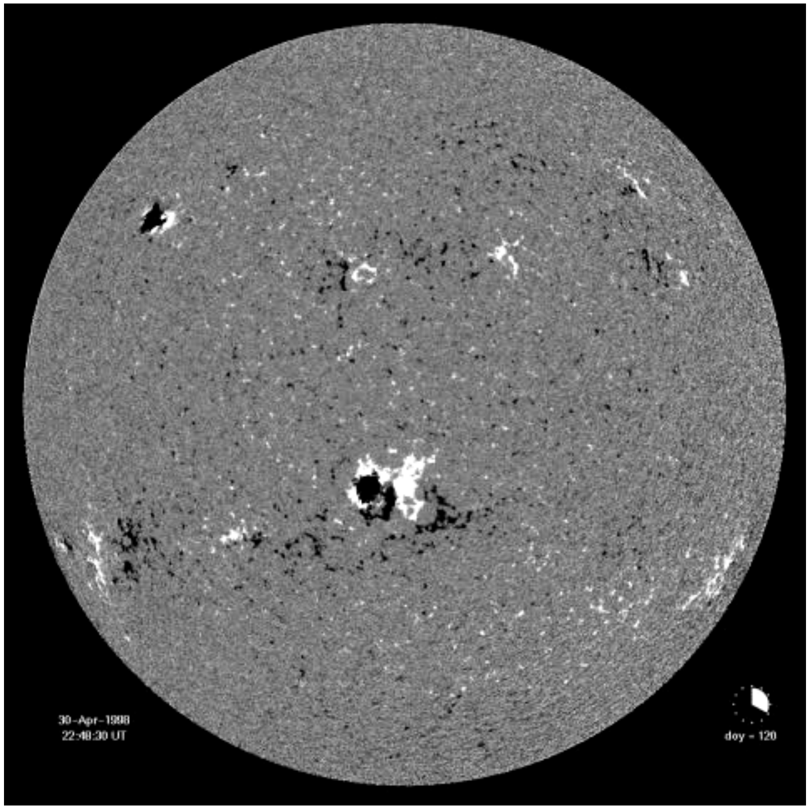


IT IS NOT POSSIBLE TO KNOW THE VARIABILITY OF THE SUNSPOT CYCLE WITH A DATA SAMPLE OF 400 YEARS .

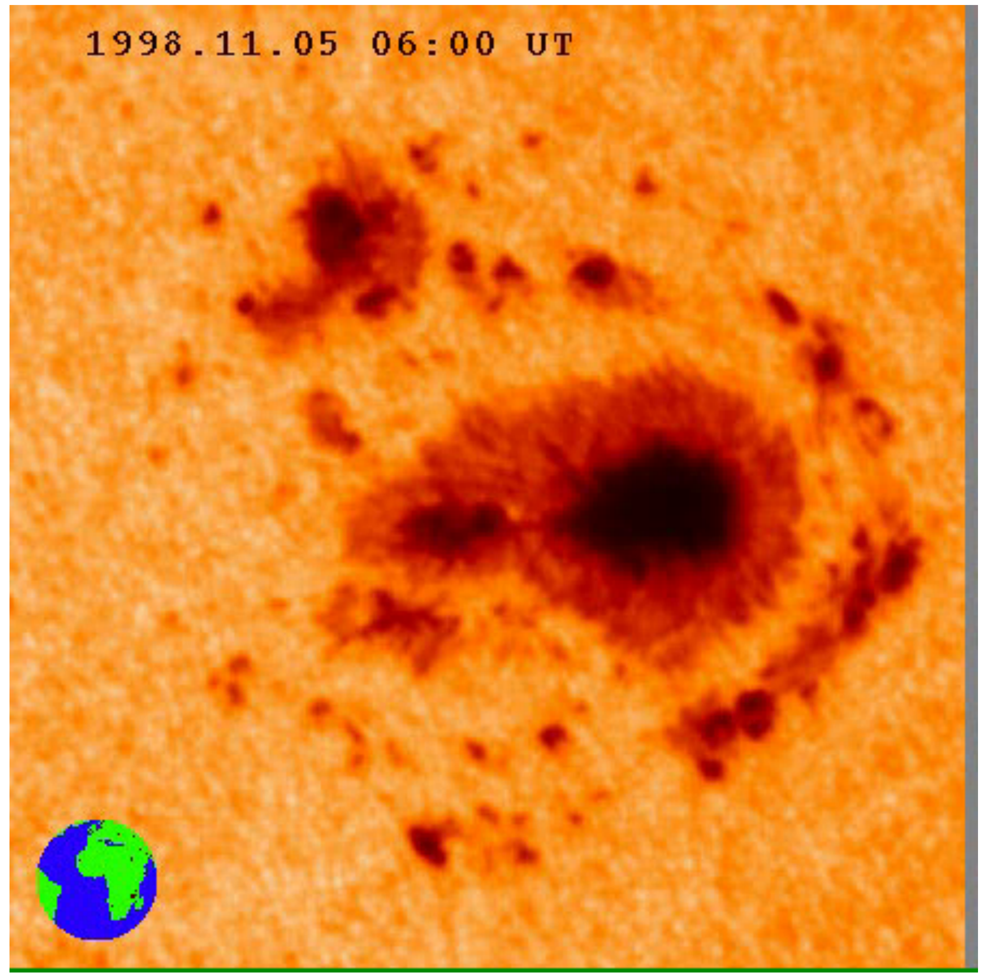
Observation of the Sun : sunspots cycle



Magnetogram of the sun



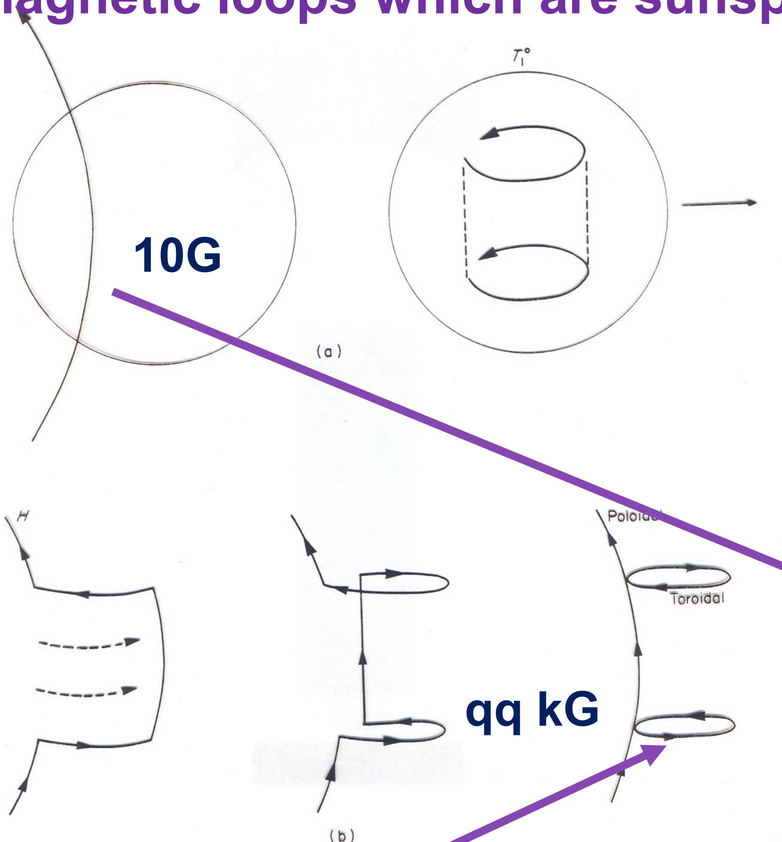
Question : How the sunspots are generated ?

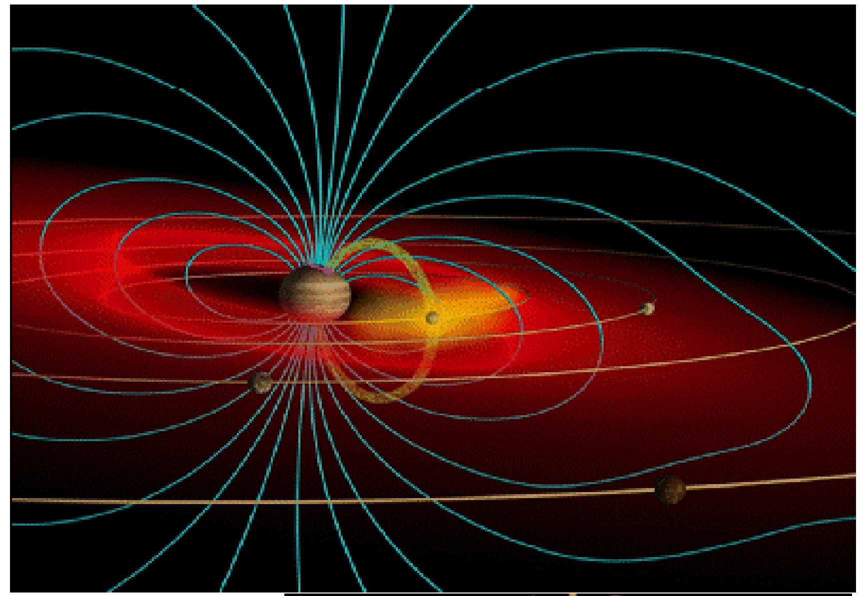


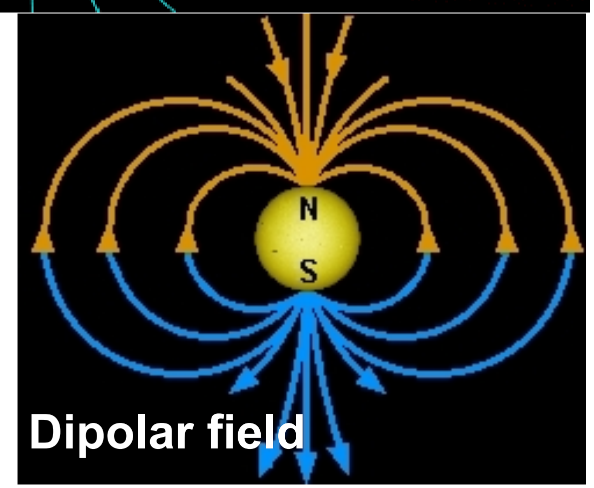
Observation of
sunspots today

Generation of a sunspot

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



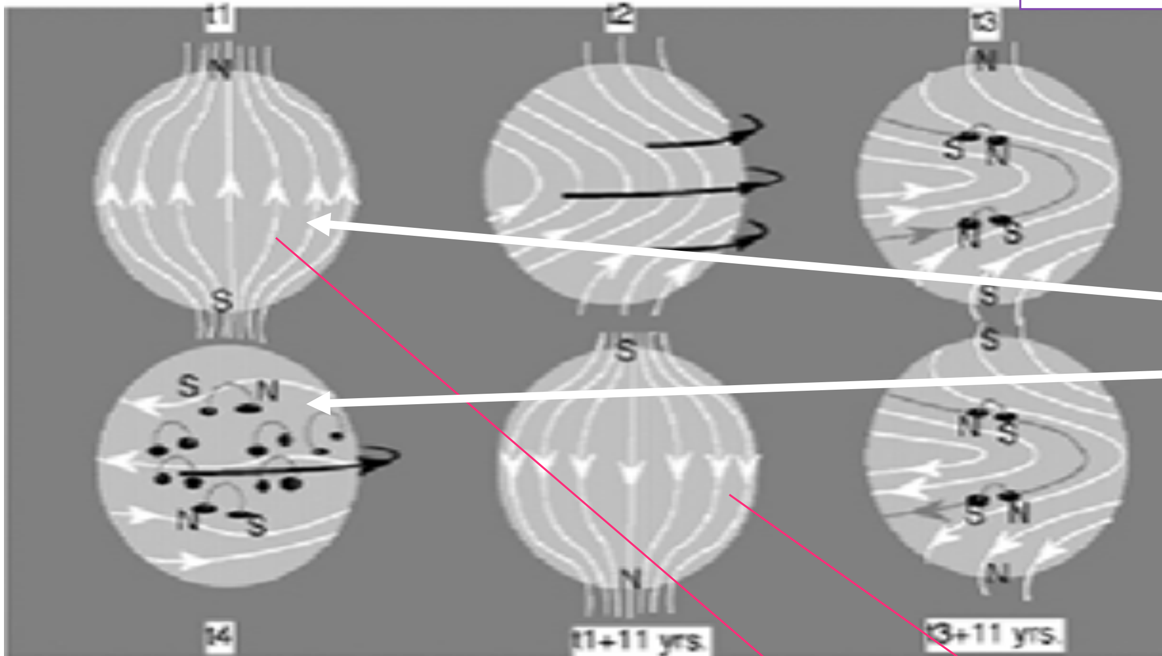




Multipolar field – Toroïdal field

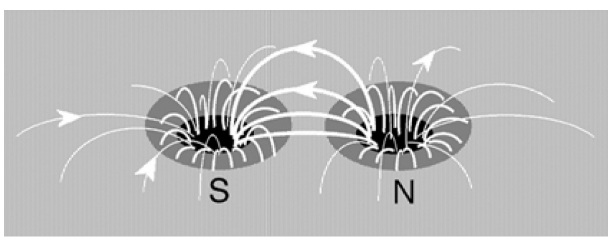
SOLAR DYNAMO

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

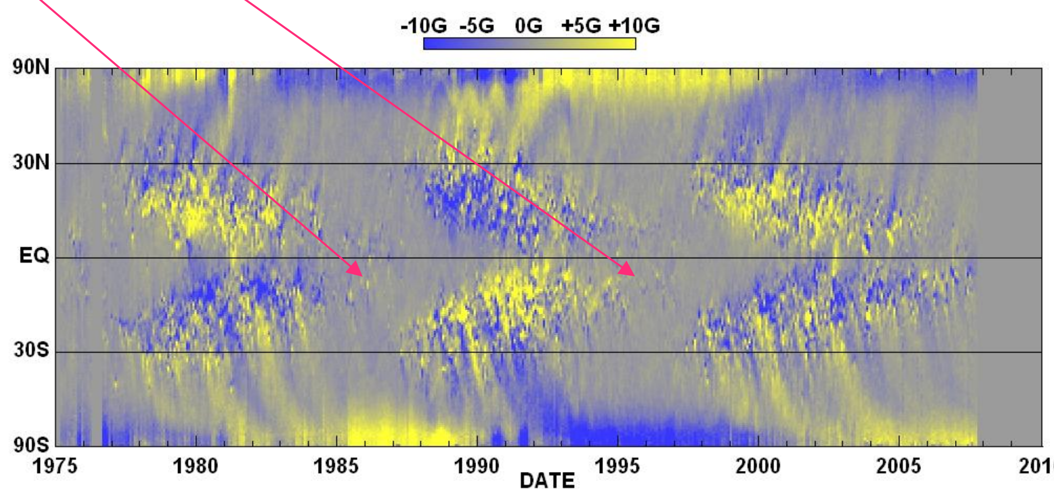


Solar differential rotation

Dipolar and Toroïdal components

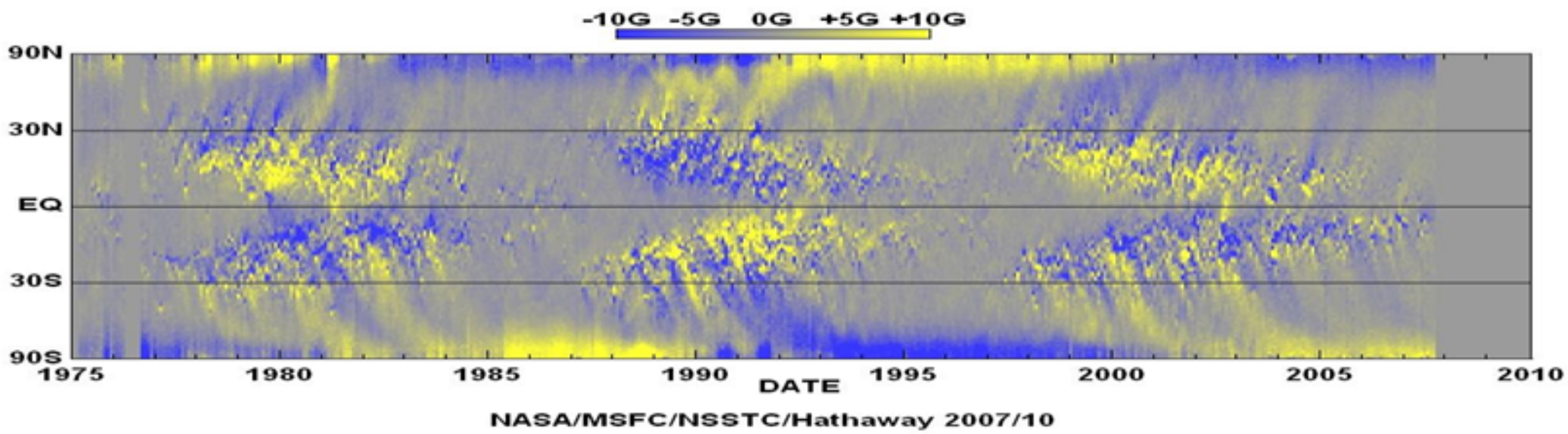


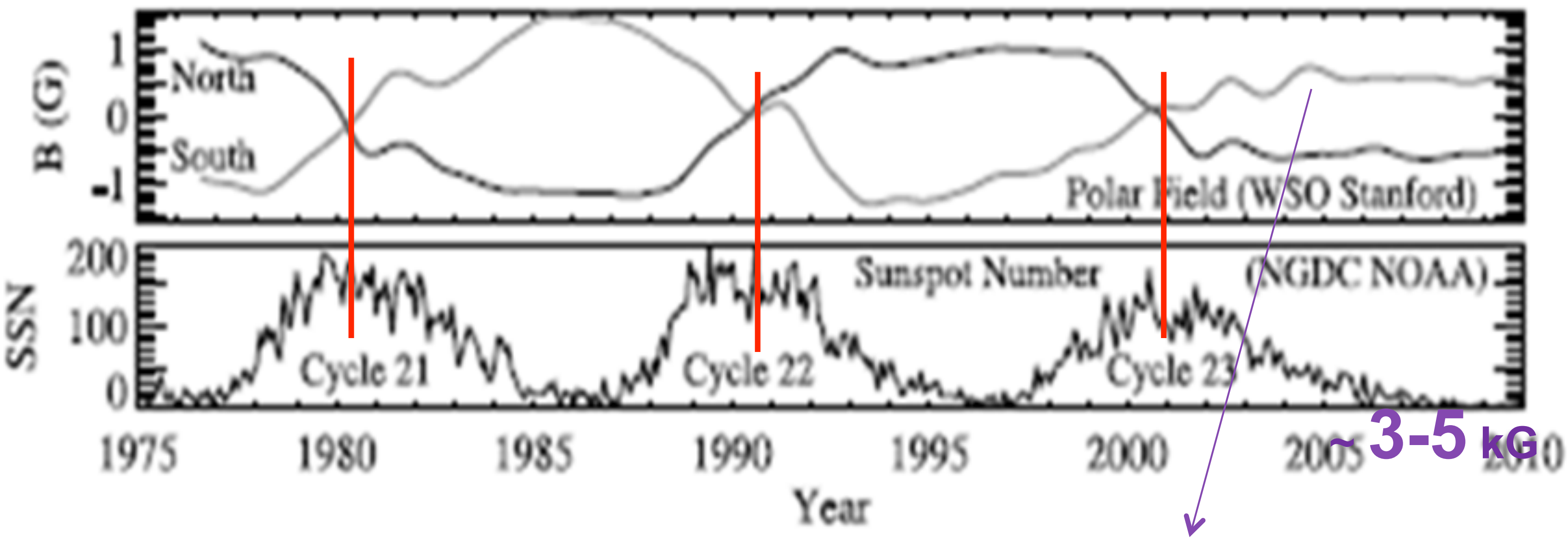
Yellow –outward /+
Blue – inward / -



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

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

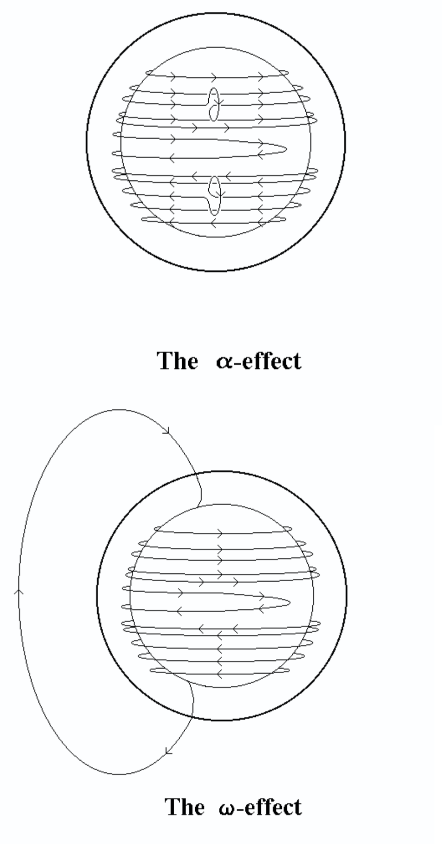




Luhmann et al., 2011

Decrease of the dipolar component of solar magnetic field => weak sunspot cycle

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

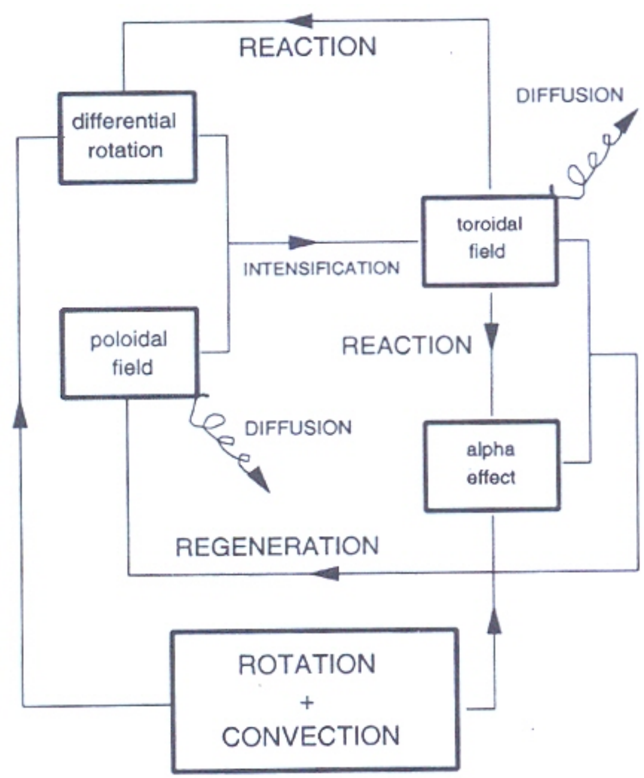


Twisting of the magnetic field lines is caused by the

effects of the Sun's rotation

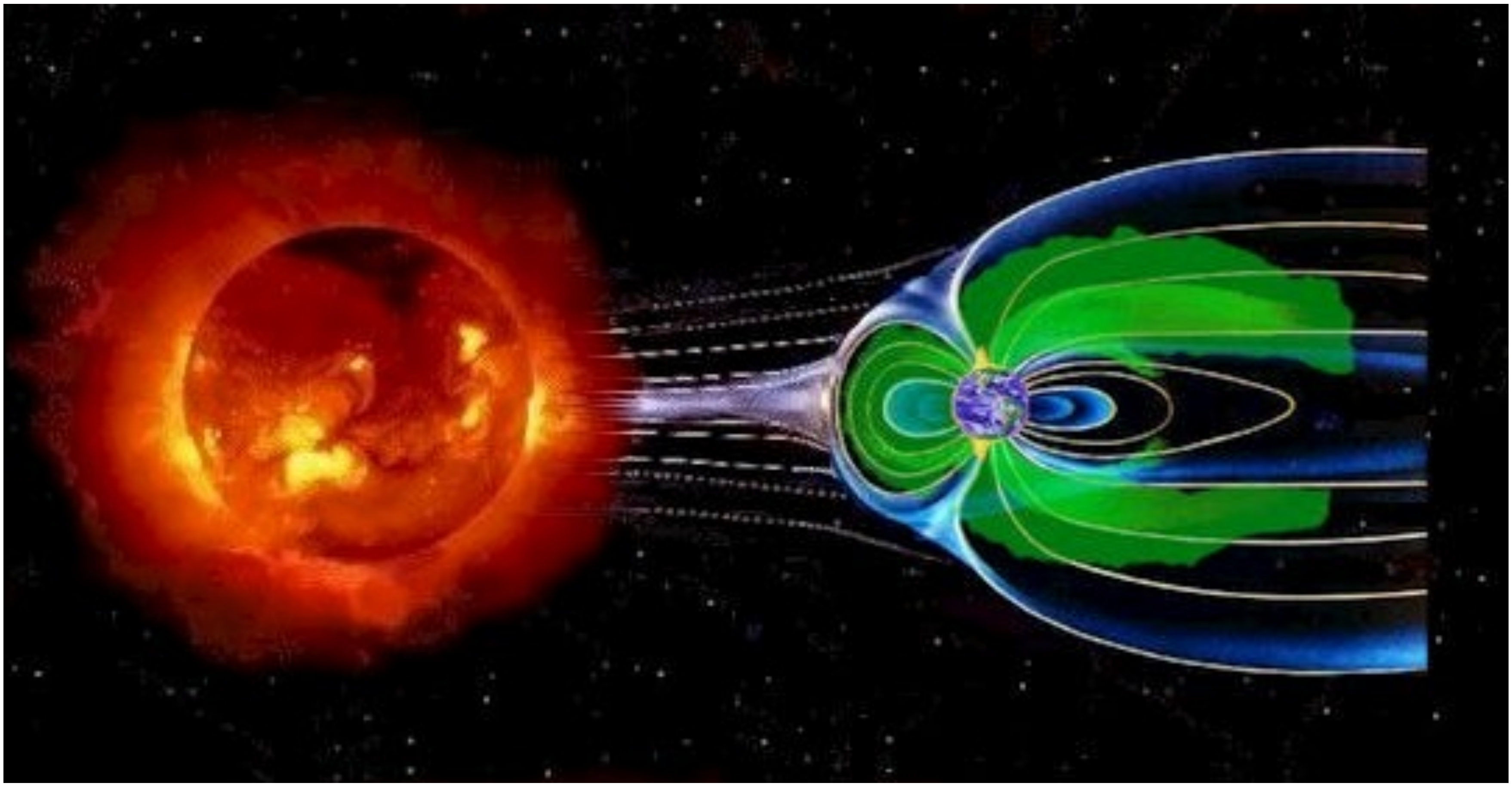
Diagram from L. Paterno, 2006

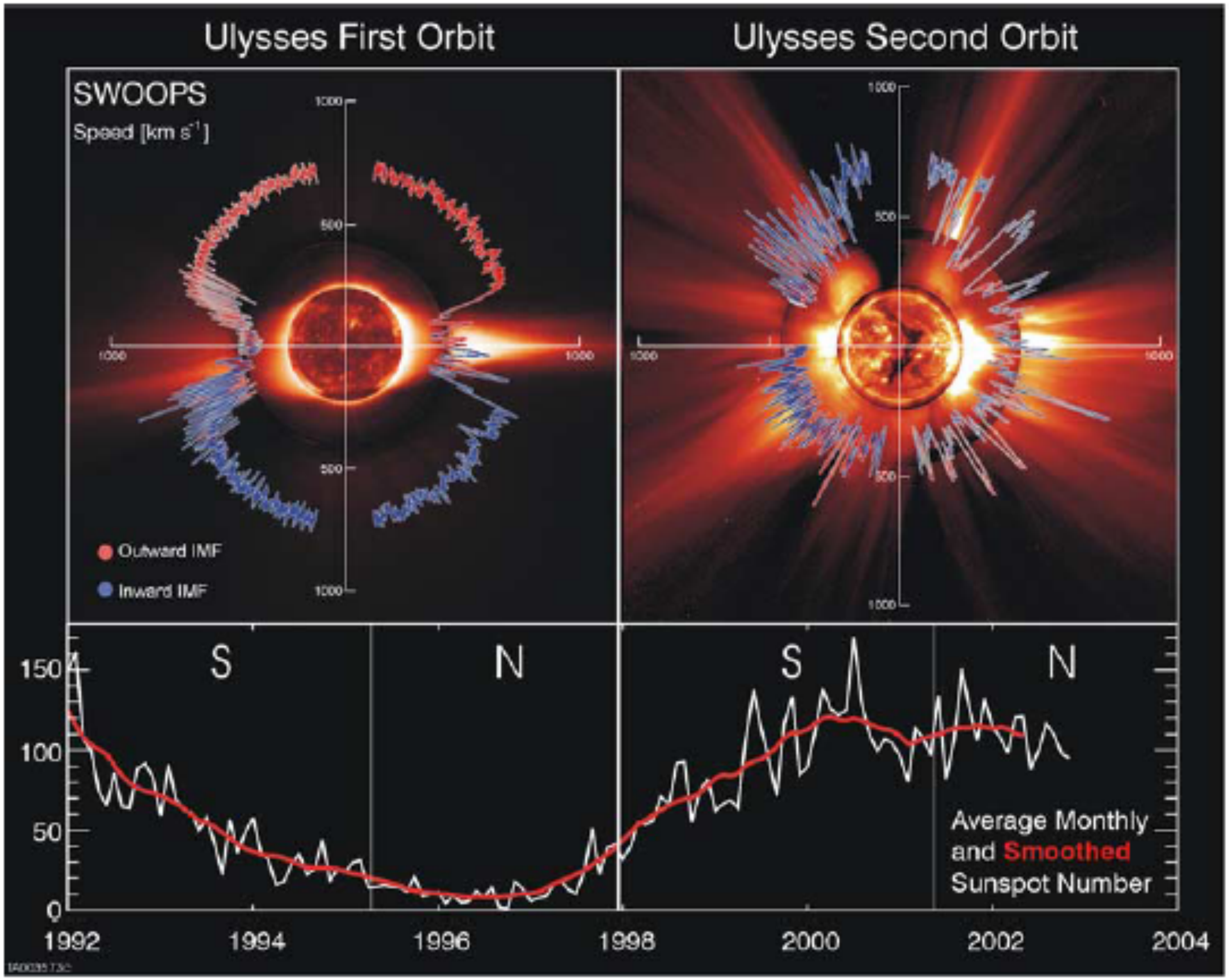
Differential rotation change in rotation rate as a function of latitude and radius within the Sun $\omega(r,\theta)$



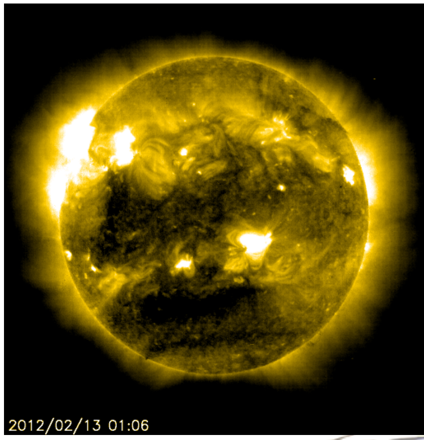
The solar dynamo ingredients
Motions : rotation and convection
Magnetic field : dipolar component

The solar wind is a flow of particules, mainly electrons protons and heavy ions . Solar wind speed is 400 à 1000 km/s .

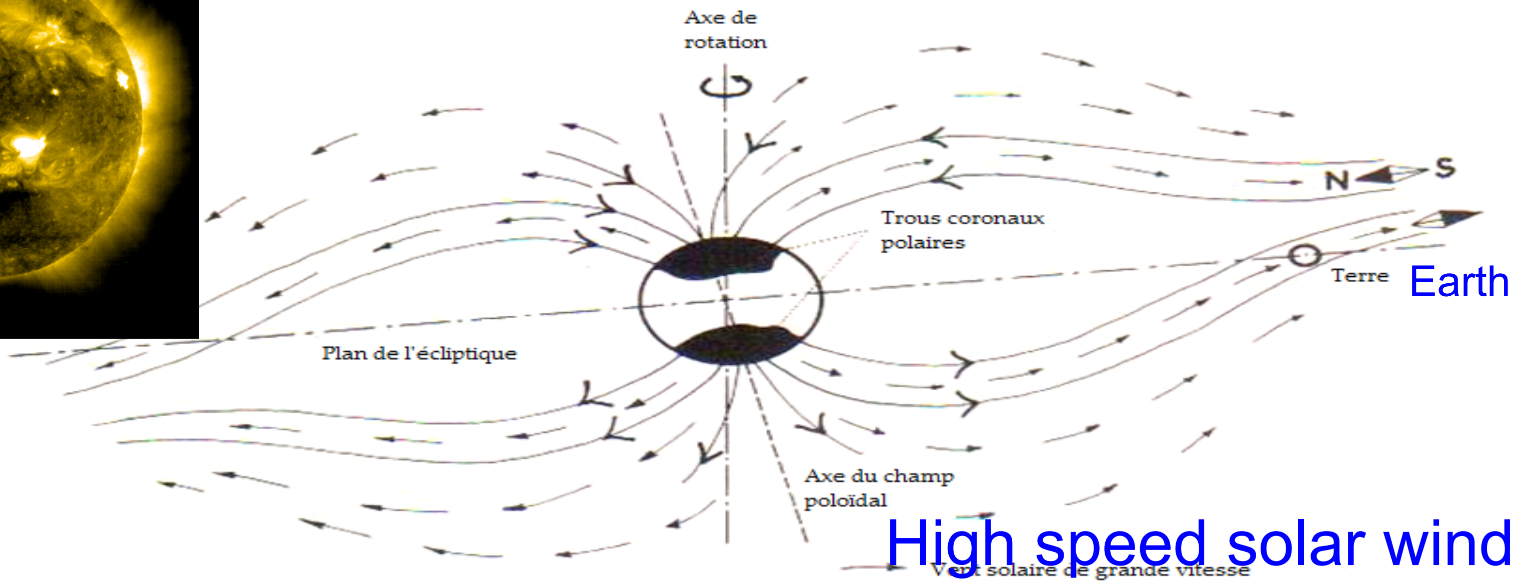


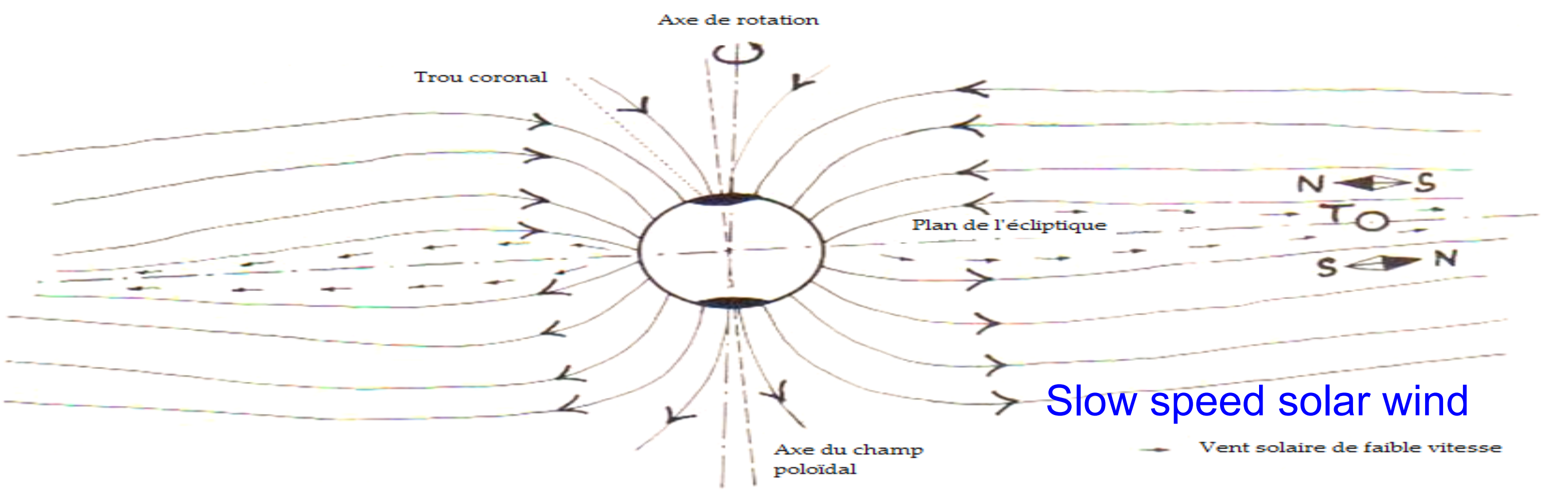


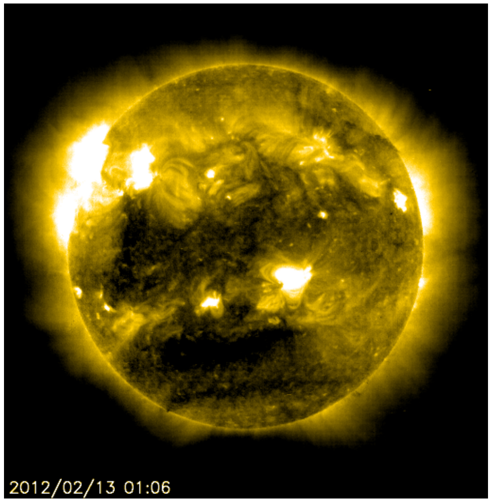
John Richardson, MIT



Coronal hole



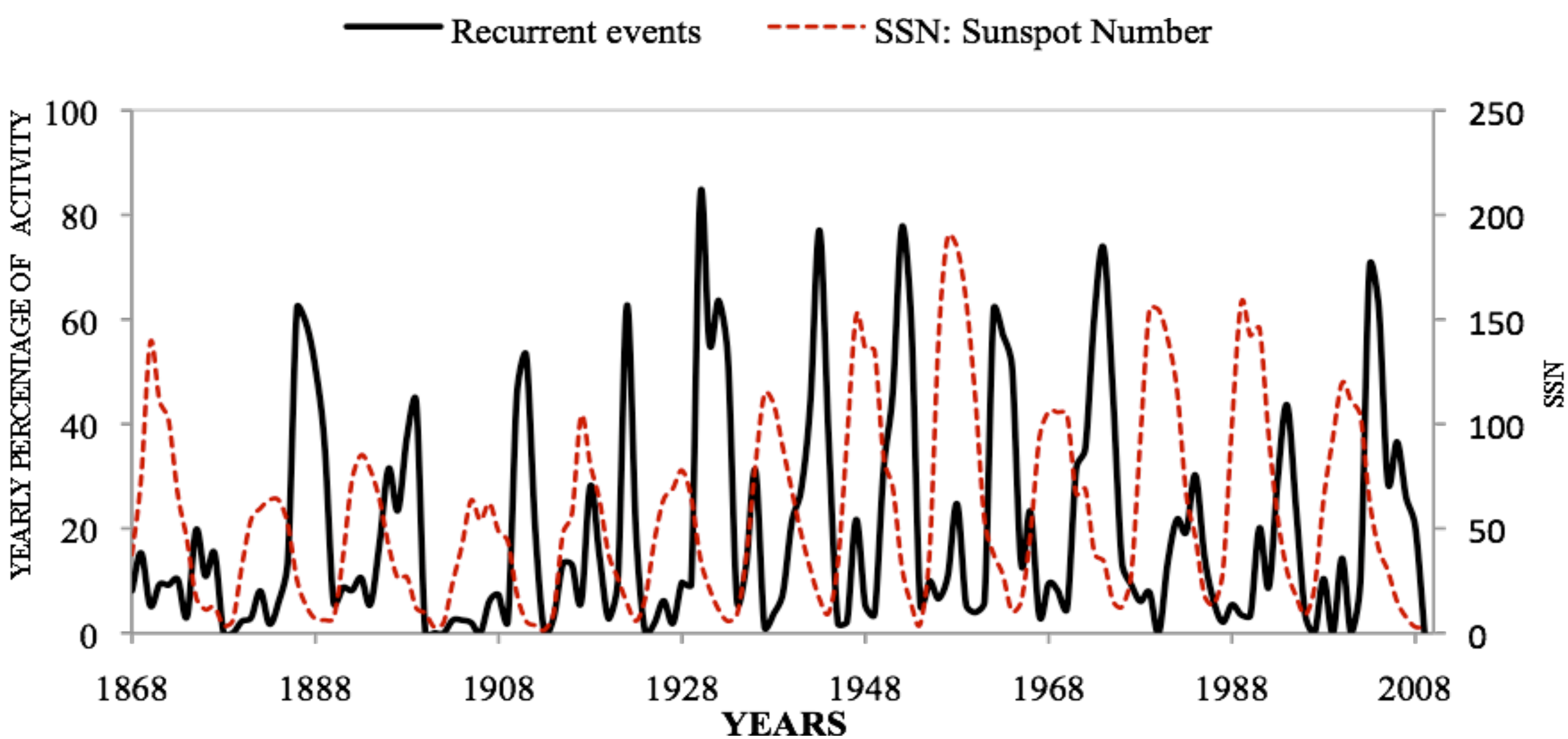


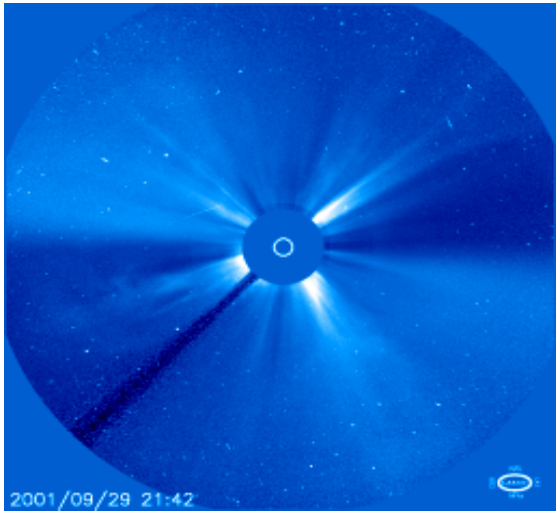


POLOIDAL FIELD

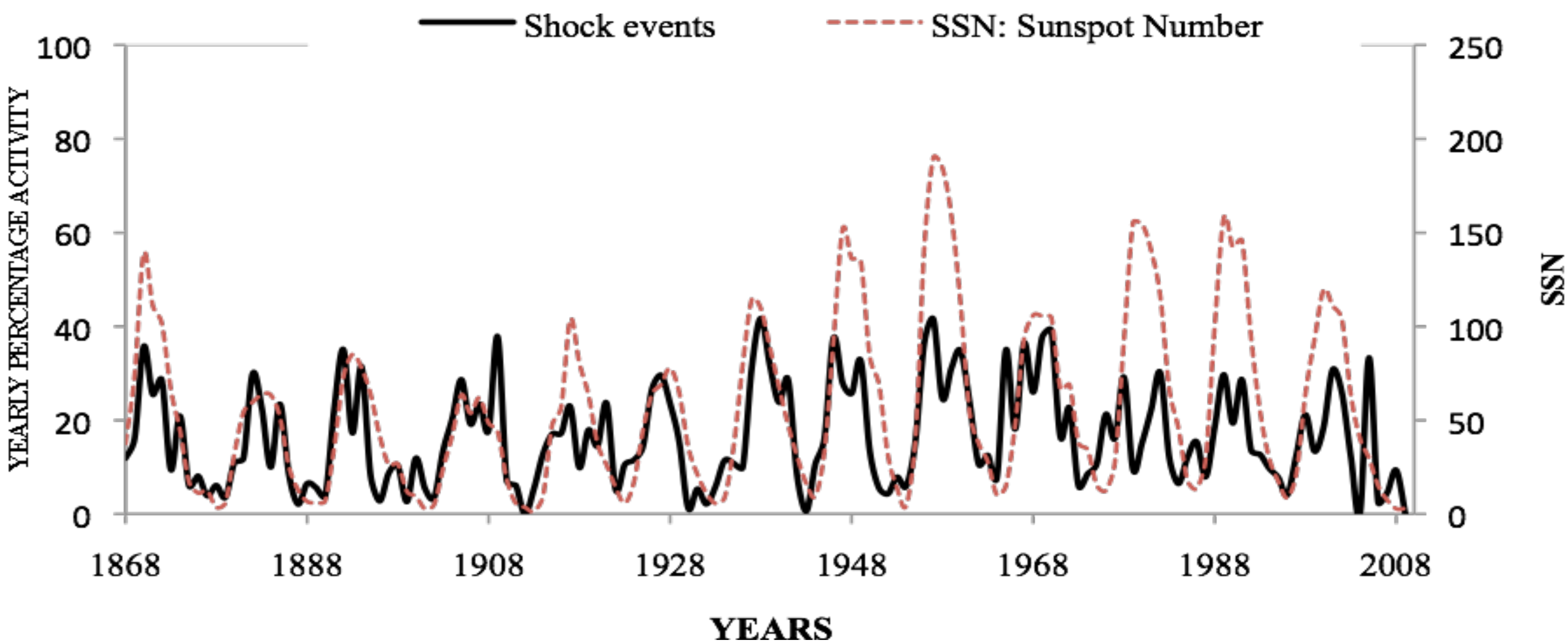
91,5% of geomagnetic activity is due to solar wind. High speed solar wind streams flowing from coronal holes are related to the poloidal component of the solar magnetic field

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





TOROIDAL FIELD = sunspot
8,5% of geomagnetic activity
Shock events -> CME
are related to the sunspot cycle

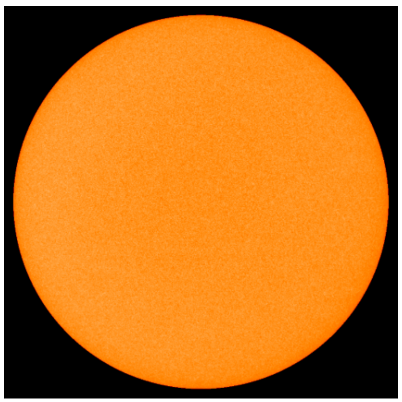


Zerbo et al., 2012

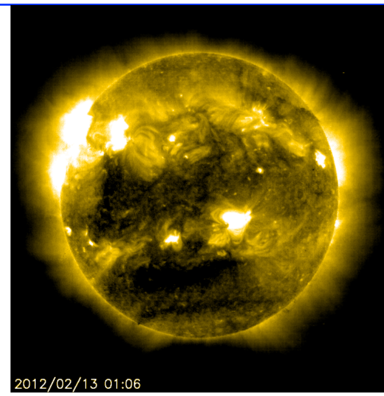
Improving of the classification of Legrand and Simon using Aa indices, SSC, Solar events and empirical relation between solar wind and geomagnetic indices

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

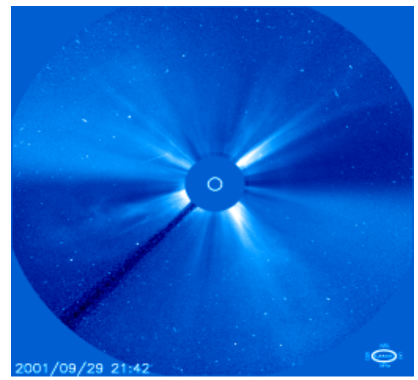
Aa < 20 nT
Quiet magnetic activity



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%

Recurrent Activity

Corotating Moderate Activity

																												Aa(nT)
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	100
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	60
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	40
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	30
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	20
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	10
31- Dec	21																											

Shock Activity

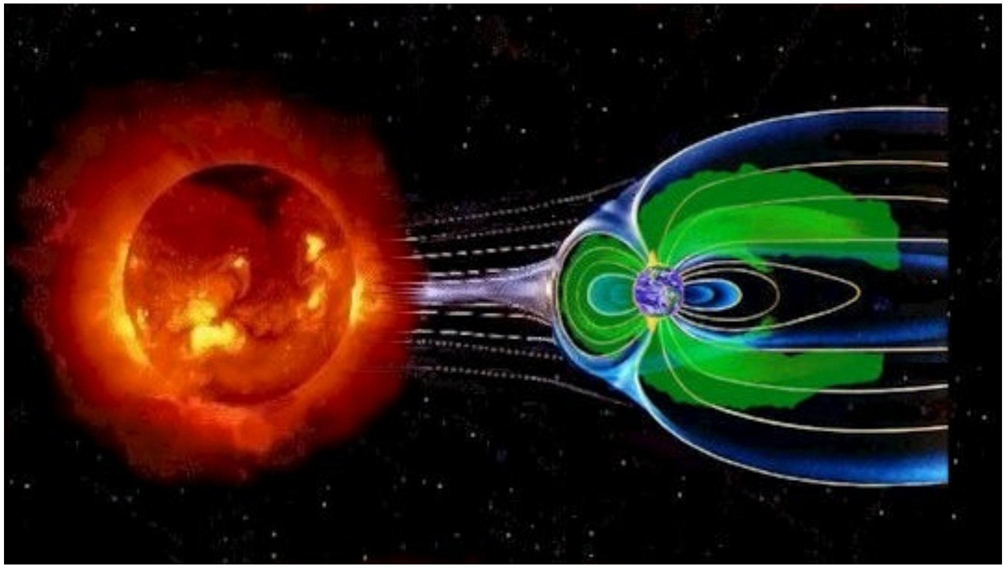
Cloud Shock Activity

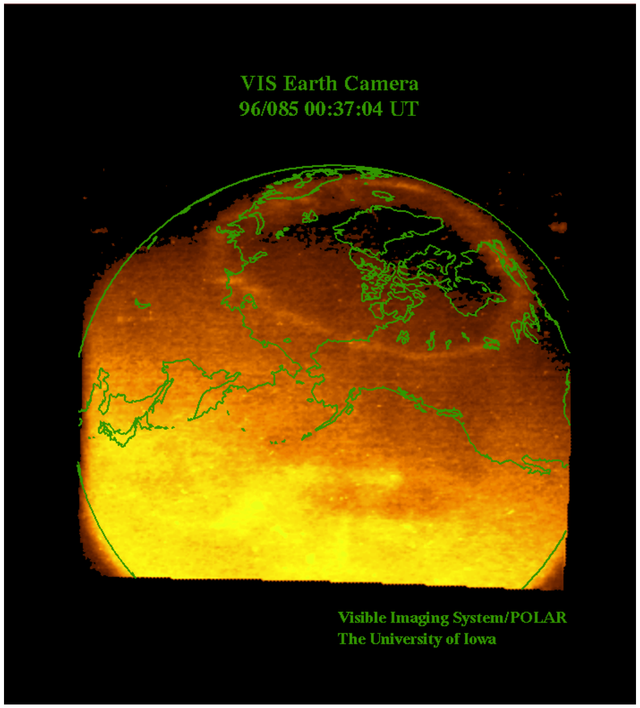
Quiet Activity

Solar Wind – Magnetosphere Dynamo

Nikolai Ostgaard

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





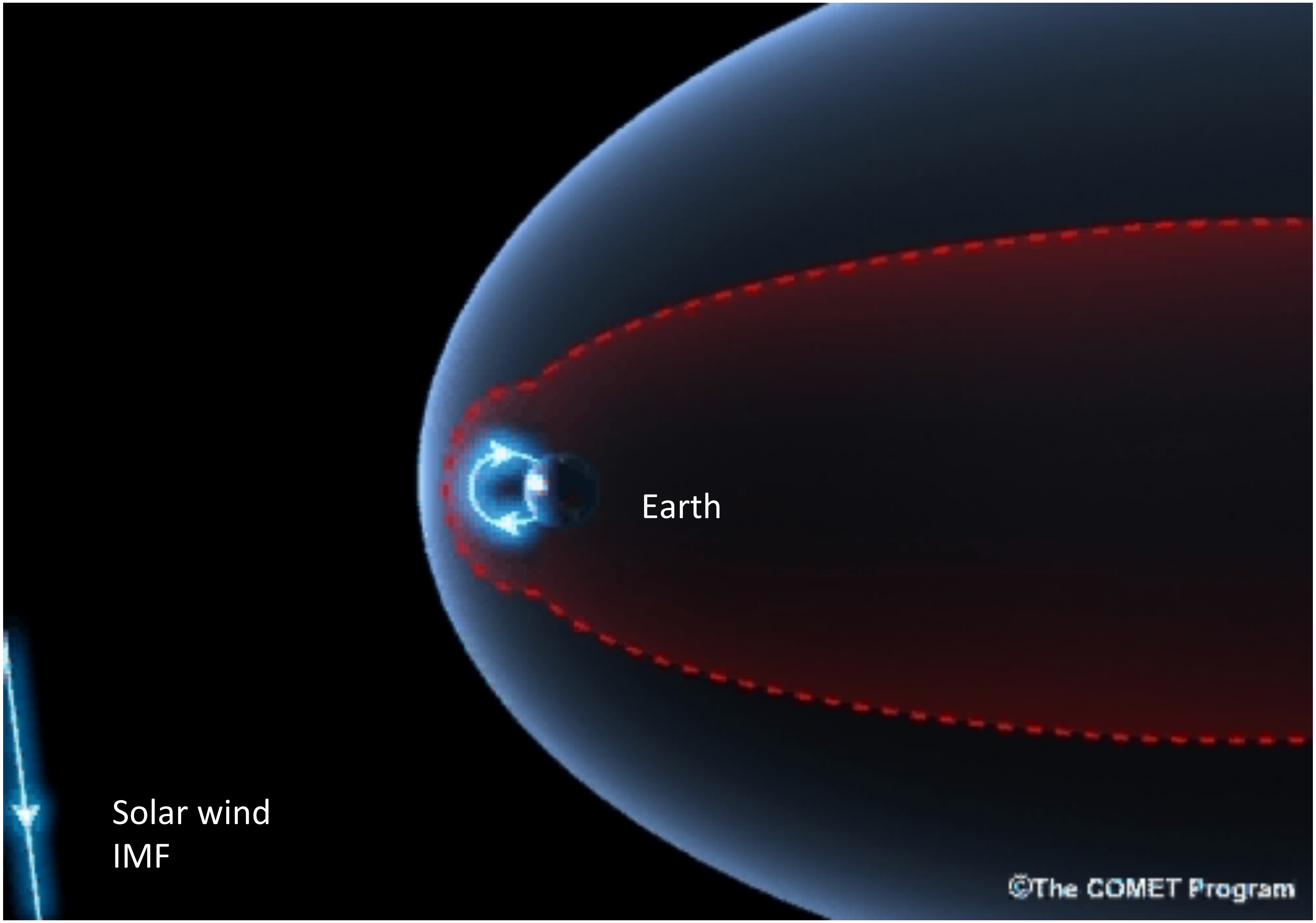
In the frame of the Magnetosphere

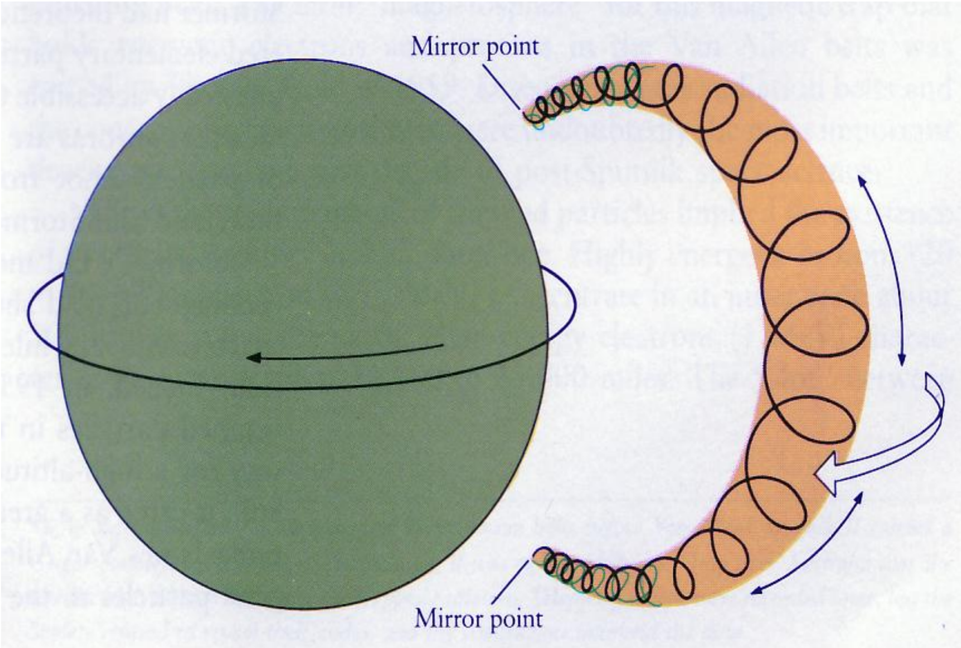
$$E = -V_s \times B_i$$

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

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

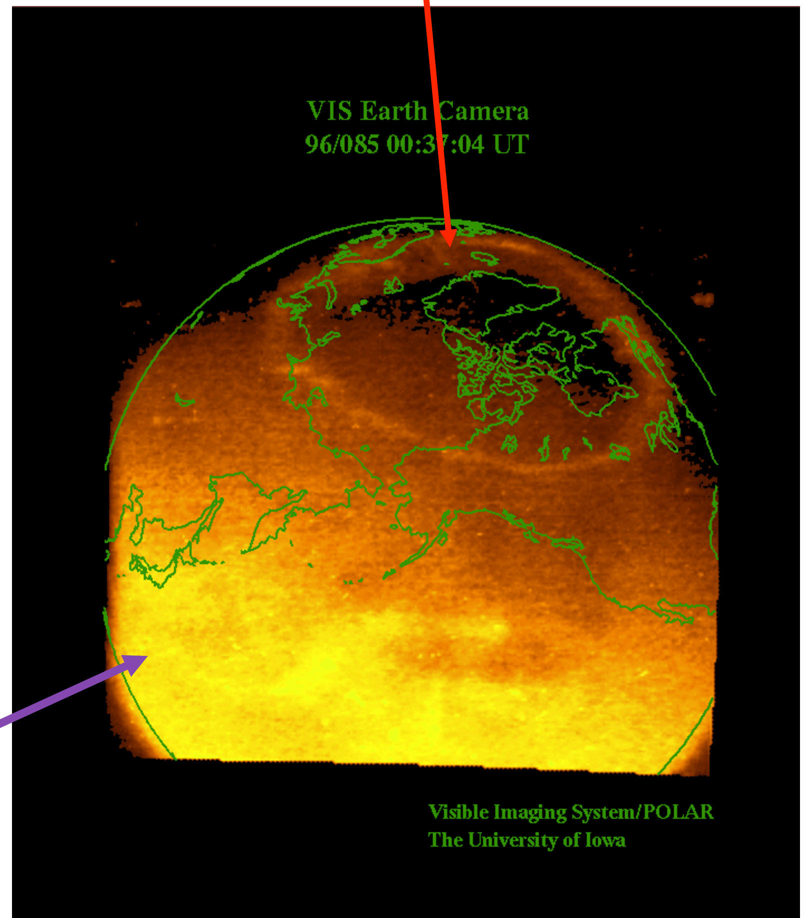
MAGNETIC RECONNECTION (Dungey, 1961)





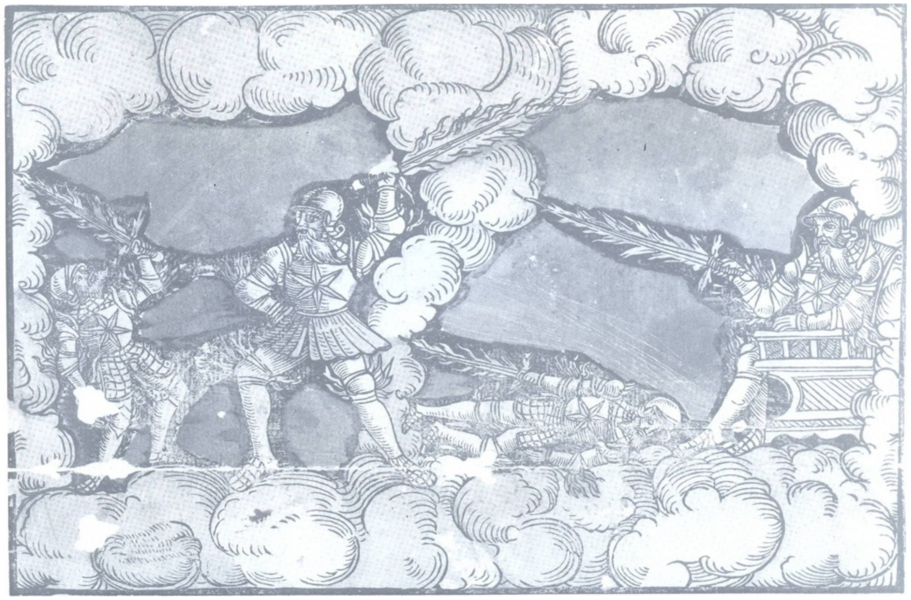
Friedman, 1987

Photo of the auroral zone



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

Solar Radiations



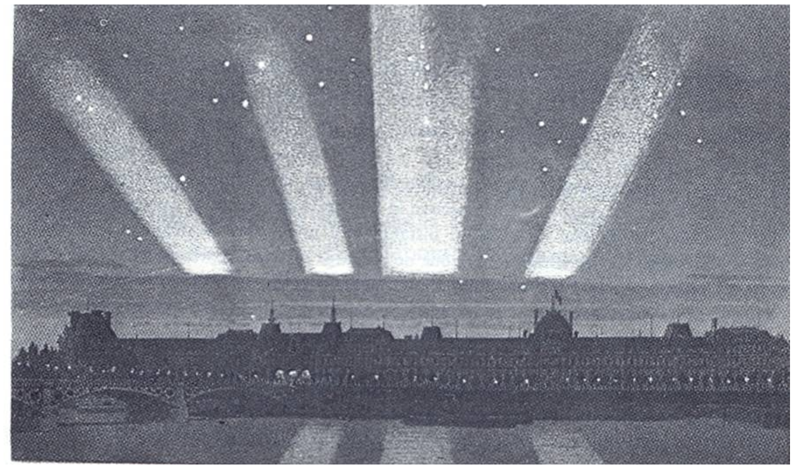
Magnetic Storms

Picture of the By aurorae observed on June 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

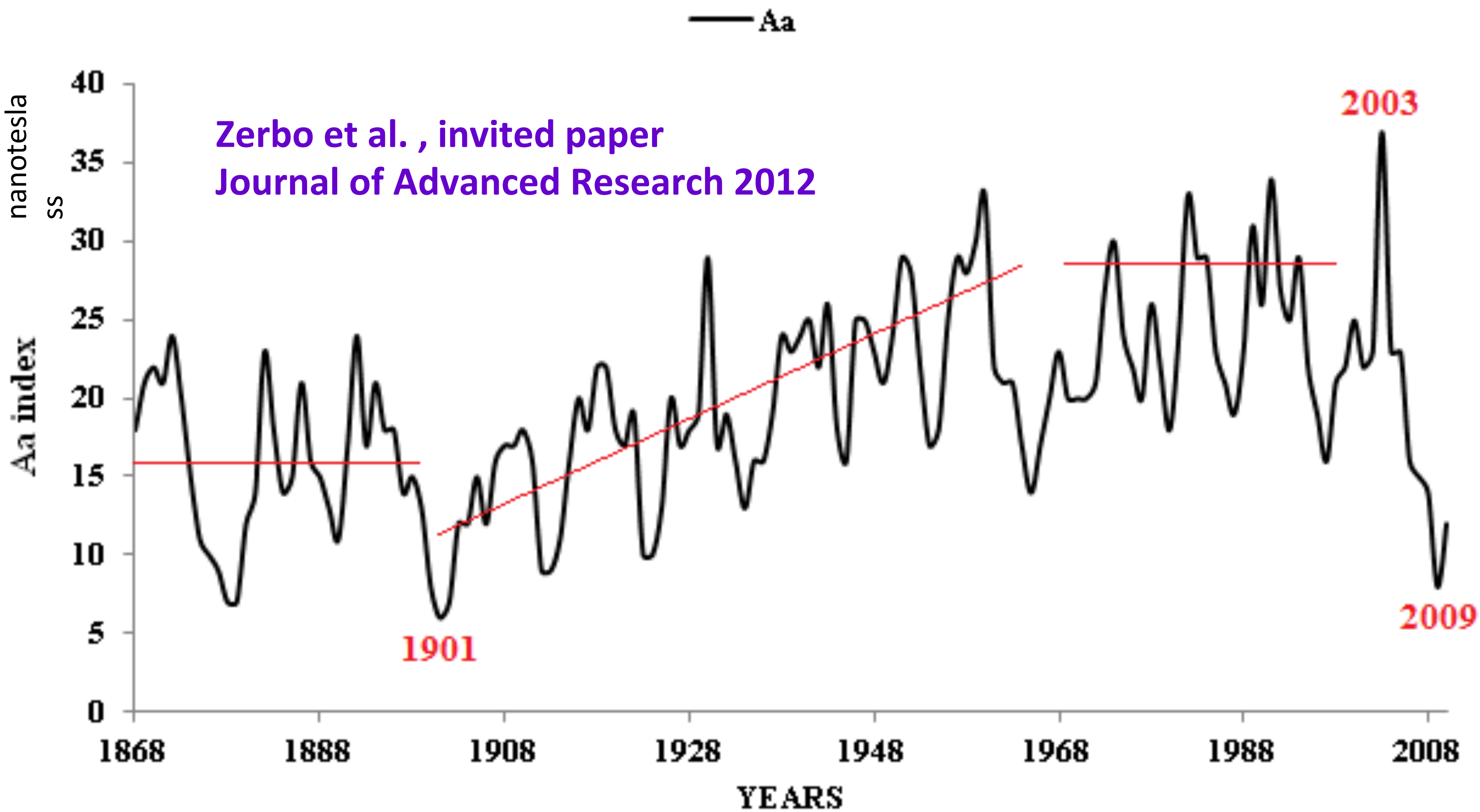
Explained
the aurora



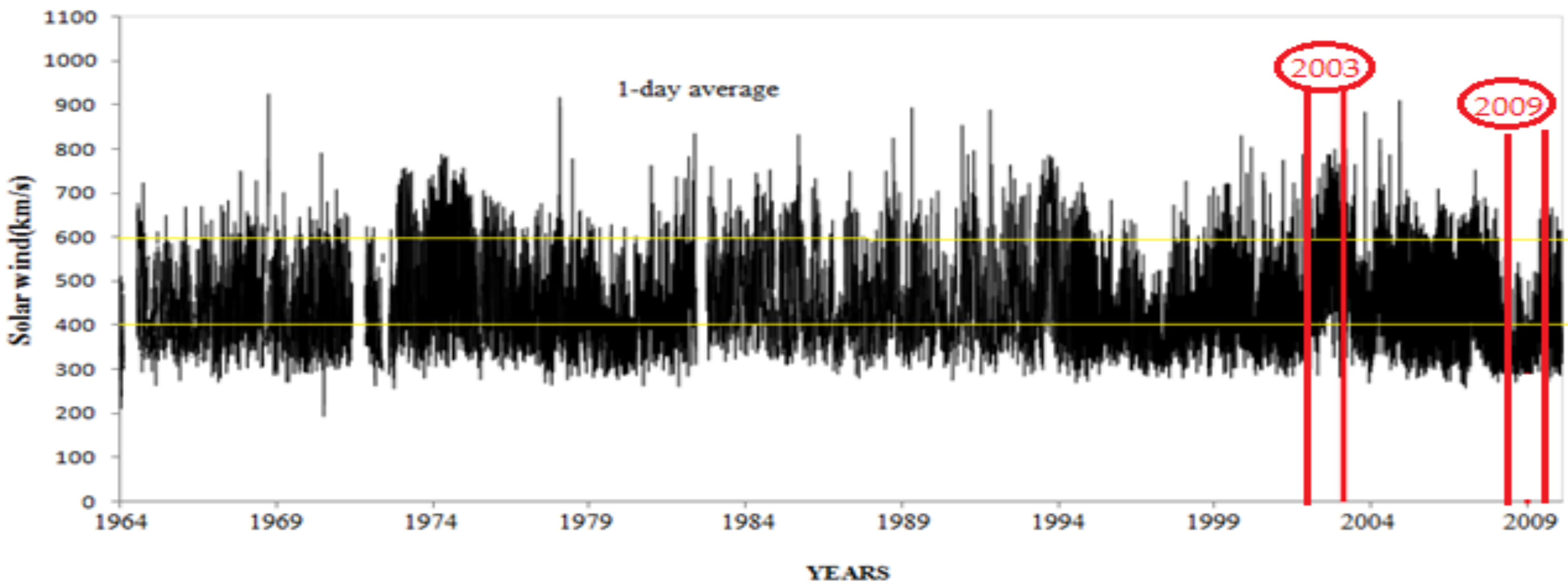
Aurora observed at Paris on May 13, 1869
(L'Atmosphere Flammarion)

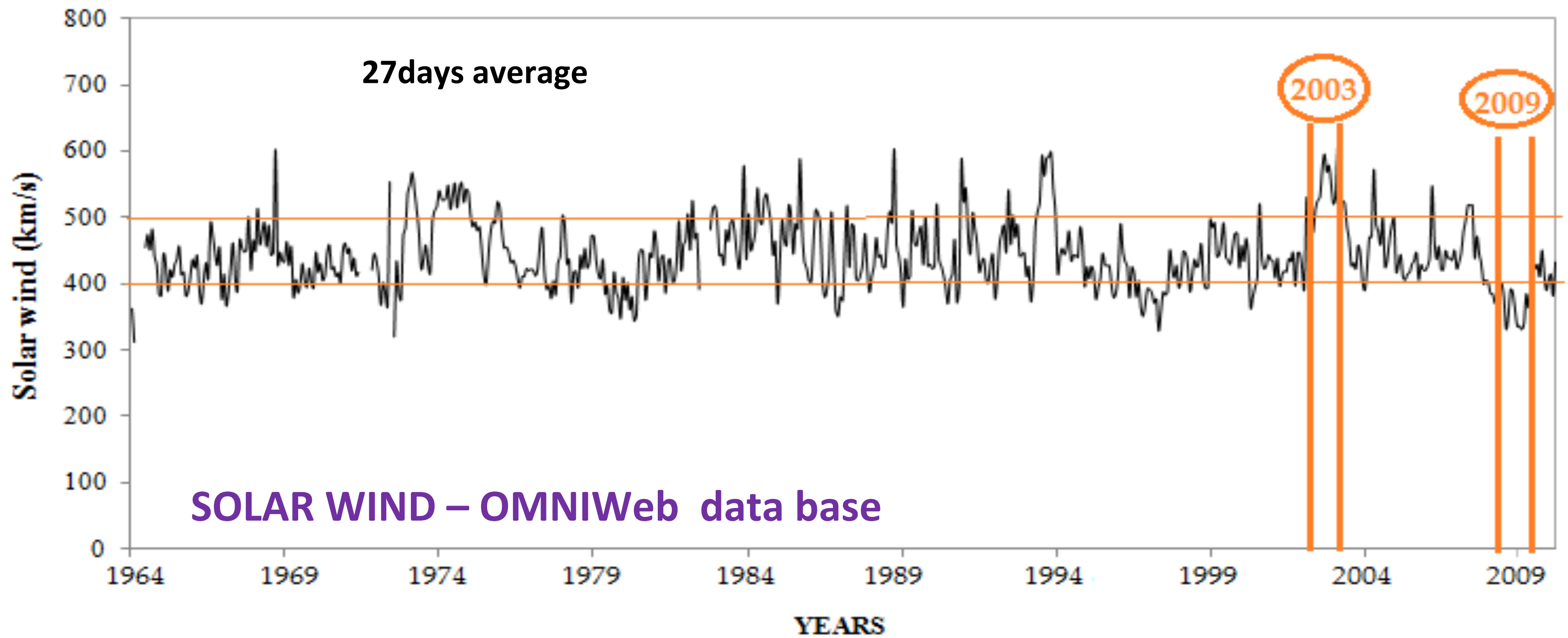
Arc auroral observed by A.E.
Nordenskiold during his travel at
Behring on March 21 1879
Les aurores polaires Angot, Paris 1895

Exceptionnal years : long term variations



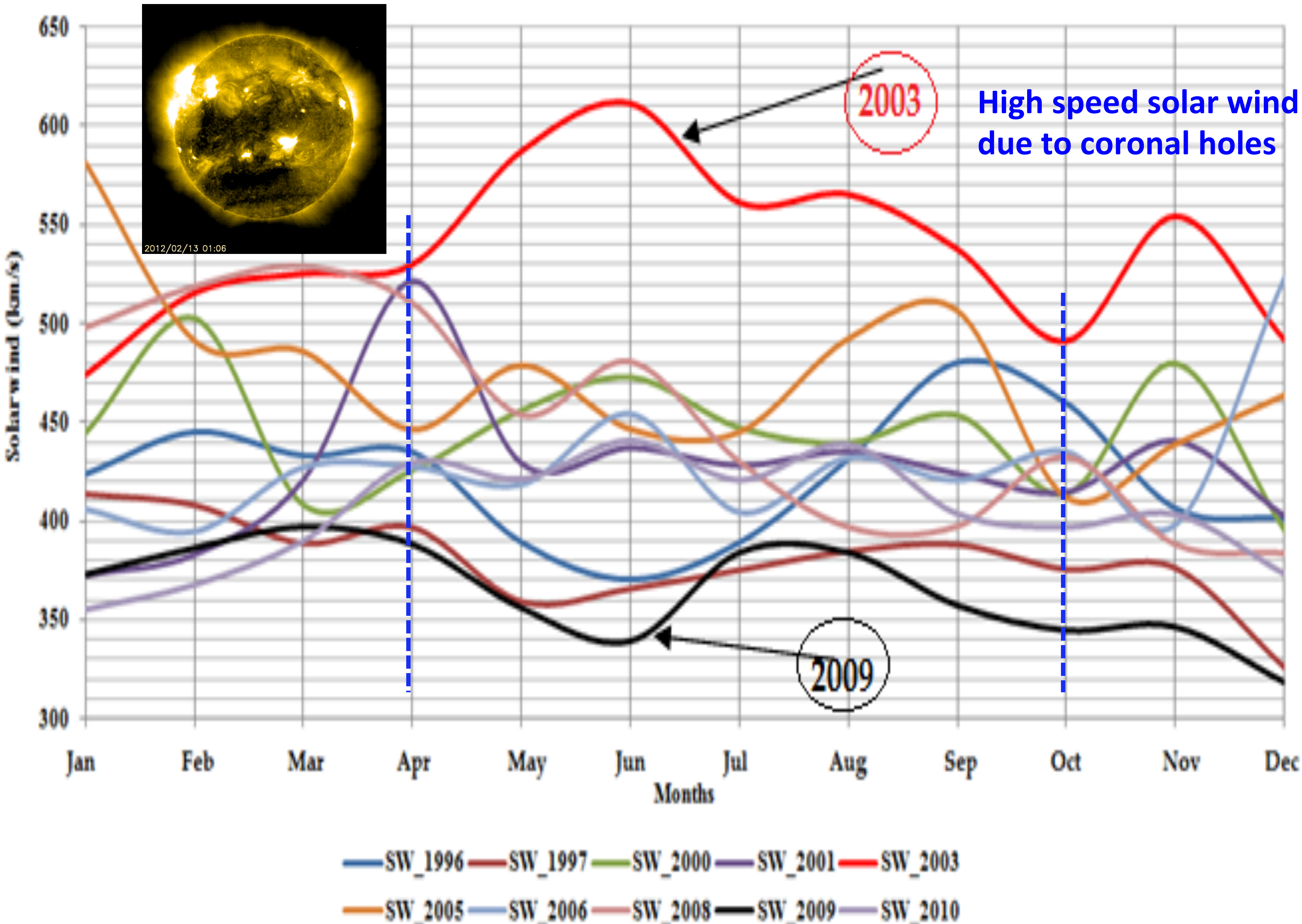
Year 2003 is the year the most magnetically disturbed since 1868
Year 2009 is the year the magnetically quiestest year since 1901

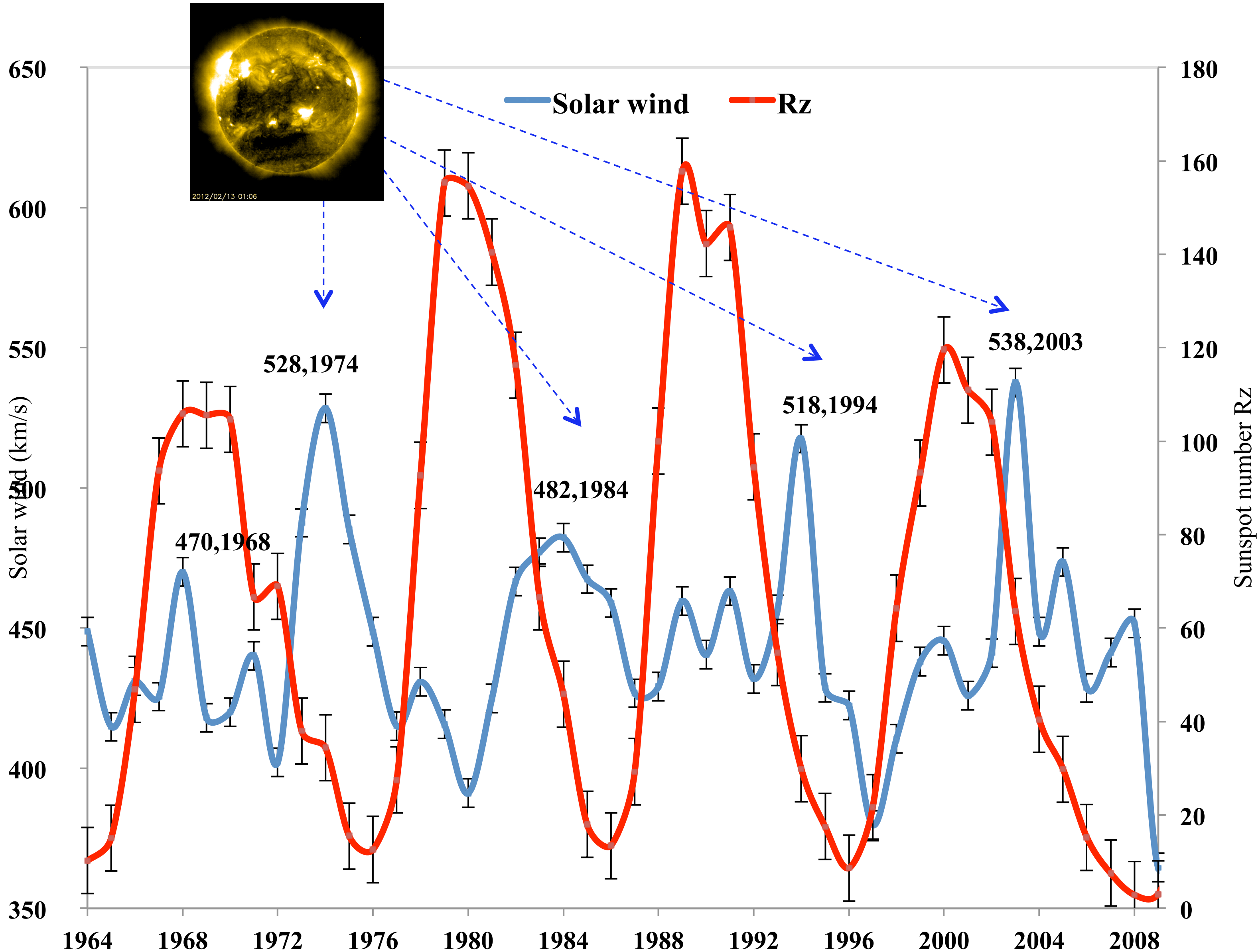




Zerbo et al. , invited paper
Journal of Advanced Research 2012

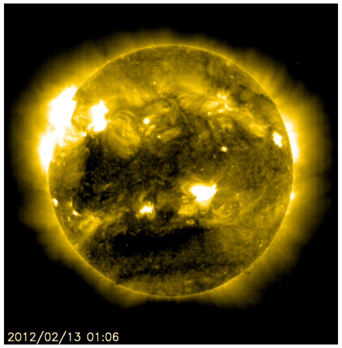
Zerbo et al. , Journal of Advanced Research 2012





Zerbo et al. ,
Journal of Advanced Research 2012

Equatorial coronal holes during the solar dipole reversal



Daily Aa 2003

01-janv	2003																							14	12	40	29	17	8	12	8
07-janv	17	8	12	8	7	28	17	19	14	18	13	8	16	29	41	30	33	37	32	32	46	39	23	20	34	47	31	28	81	35	52
03-févr	28	81	35	52	27	32	27	30	33	29	18	26	14	37	39	32	23	46	24	32	25	22	22	14	10	30	52	37	31	23	36
02-mars	37	31	23	36	52	33	48	26	20	20	30	21	16	26	43	49	49	57	41	22	47	49	28	38	12	7	16	46	42	53	57
29-mars	46	42	53	57	54	29	44	32	57	43	16	12	38	39	41	25	17	19	30	29	58	46	37	16	24	43	42	33	46	49	35
25-avr	33	46	49	35	31	29	34	56	64	27	22	11	25	50	61	65	55	49	381	41	41	46	39	16	15	17	22	21	45	48	31
22-mai	21	45	48	31	44	31	31	52	50	122	75	39	35	60	44	37	23	25	40	53	46	37	26	13	15	46	37	63	71	81	23
18-juin	63	71	81	23	23	45	27	37	44	35	34	50	62	41	33	14	26	29	37	32	17	28	5	7	15	66	61	27	26	51	74
15-juil	27	26	51	74	37	32	50	32	11	11	16	15	15	44	35	29	59	49	52	61	38	27	21	12	46	52	52	28	21	18	45
11-août	28	21	18	45	28	29	23	16	40	110	24	26	78	70	59	33	37	24	19	29	28	23	14	23	20	29	44	31	17	7	11
07-sept	31	17	7	11	40	36	27	18	17	9	11	58	90	72	54	42	34	33	29	55	50	29	9	8	7	10	18	16	28	11	12
04-oct	16	28	11	12	20	32	15	13	6	3	9	31	80	64	47	50	41	53	50	66	55	12	59	36	23	17	43	299	230	179	41
31-oct	299	230	179	41	31	24	55	13	32	15	20	51	48	78	48	76	57	62	61	53	46	24	228	59	46	40	27	27	16	11	11
27-nov	27	16	11	11	11	29	17	14	9	13	66	39	29	65	54	67	64	43	45	48	38	19	14	7	4	39	45	35	15	17	12
24-déc	35	15	17	12	15	21	25	11	15	39																					

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

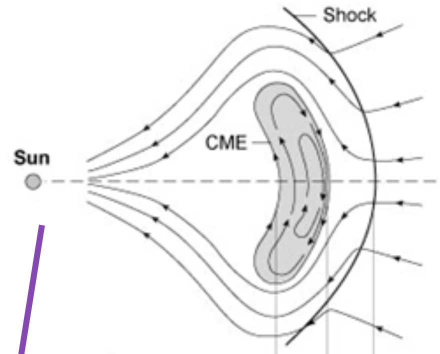
No coronal hole

2009

01-Janua	2009																												16	10	21
02-Janua	28	16	10	21	10	11	7	5	7	13	11	3	2	11	13	13	9	6	6	19	9	9	5	5	4	8	29	9	5	7	9
29-Janua	9	5	7	9	14	5	3	9	28	12	3	5	3	5	5	6	8	5	36	25	8	3	7	4	11	7	9	13	12	6	6
25-Febru	13	12	6	6	22	10	6	4	17	14	5	4	2	15	3	8	8	15	32	19	14	11	6	4	10	7	21	9	3	16	17
24-March	9	3	16	17	10	11	5	5	8	5	6	3	4	4	7	5	5	13	28	17	21	12	7	4	8	9	10	15	9	6	6
20-April	15	9	6	6	7	3	11	8	5	6	4	7	4	5	7	4	6	4	13	15	21	12	6	8	3	4	14	4	8	3	4
17-May	4	8	3	4	6	10	7	10	8	5	2	5	2	11	9	6	5	3	3	8	9	8	5	9	4	4	6	4	2	6	9
13-June	4	2	6	9	6	6	4	5	3	8	13	4	7	32	14	5	9	22	15	8	4	4	6	5	8	5	8	7	10	14	6
10-July	7	10	14	6	5	18	13	7	3	2	3	2	11	7	39	13	9	7	5	7	6	4	8	9	7	5	11	7	11	22	13
06-Augus	7	11	22	13	5	12	6	5	6	6	4	3	3	4	4	16	22	16	9	8	3	5	6	12	4	2	37	9	6	5	10
02-Septe	9	6	5	10	14	4	7	3	3	4	5	8	4	10	10	10	11	10	5	2	9	13	5	2	3	3	7	13	19	2	11
29-Septe	13	19	2	11	3	3	3	11	4	3	2	4	5	4	18	3	7	3	14	5	2	4	5	2	3	28	18	20	11	7	6
26-Octob	20	11	7	6	6	11	16	5	8	8	3	3	2	3	3	18	6	3	2	3	4	13	12	4	3	5	5	5	18	9	2
22-Noven	5	18	9	2	18	13	14	4	7	3	3	2	3	2	2	9	6	7	2	2	3	2	8	7	12	3	10	7	7	4	5
19-Decen	7	7	4	5	10	11	12	8	12	10	8	6	5	4	6																

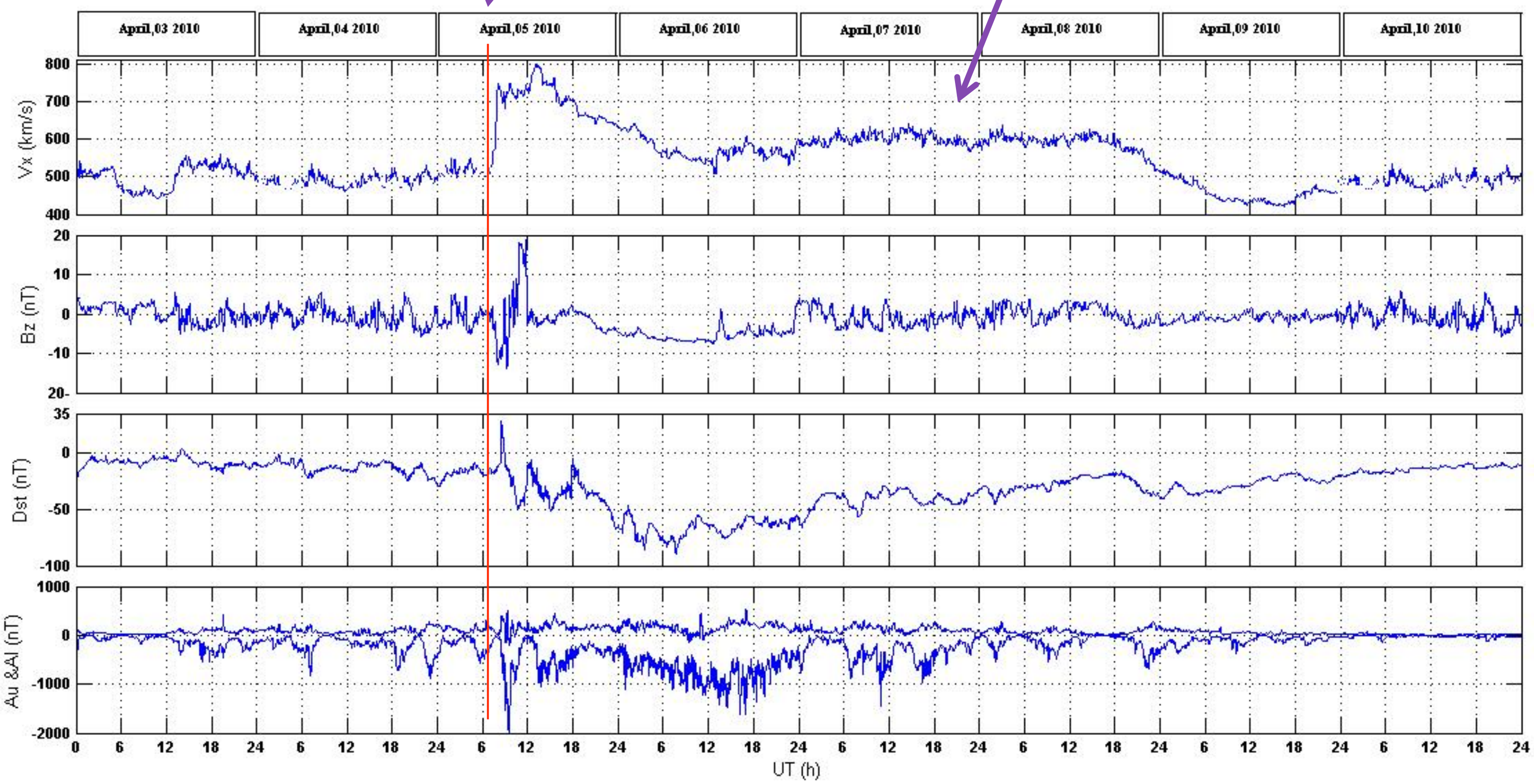
aa (nT): 100, 60, 40, 30, 20, 10

Shimeis et al., JGR 2012



Coronal Holes:

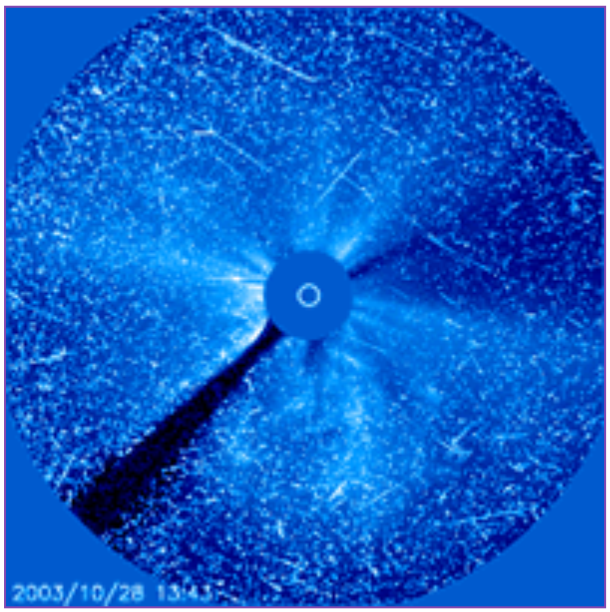
A solar wind stream flowing from the indicated coronal hole should reach Earth on April 6th or 7th. Credit: SOHO Extreme UV Telescope



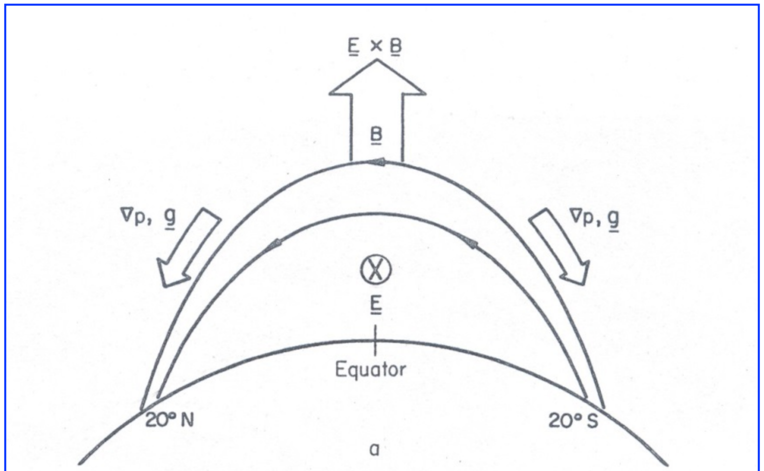
SSC at 08:26

Sun Earth System

Coronal mass ejection affect the equatorial fountain

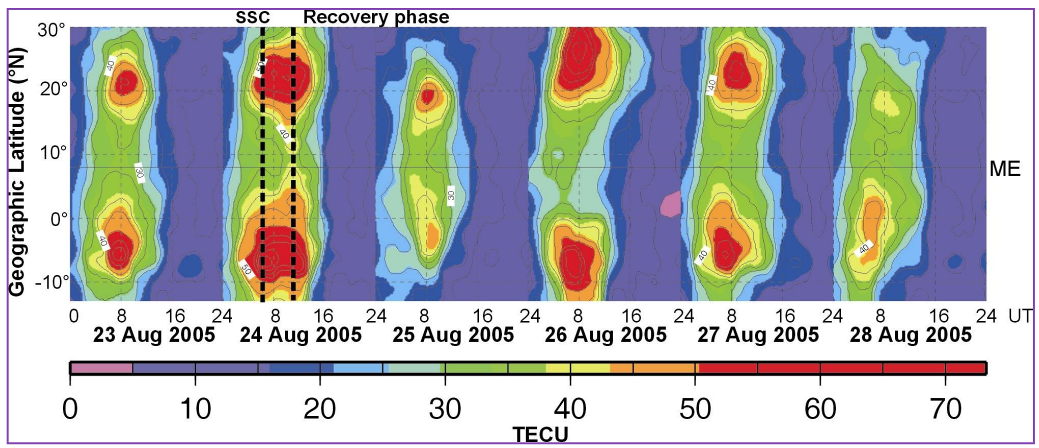


Images du satellite SOHO/NASA



Equatorial fountain

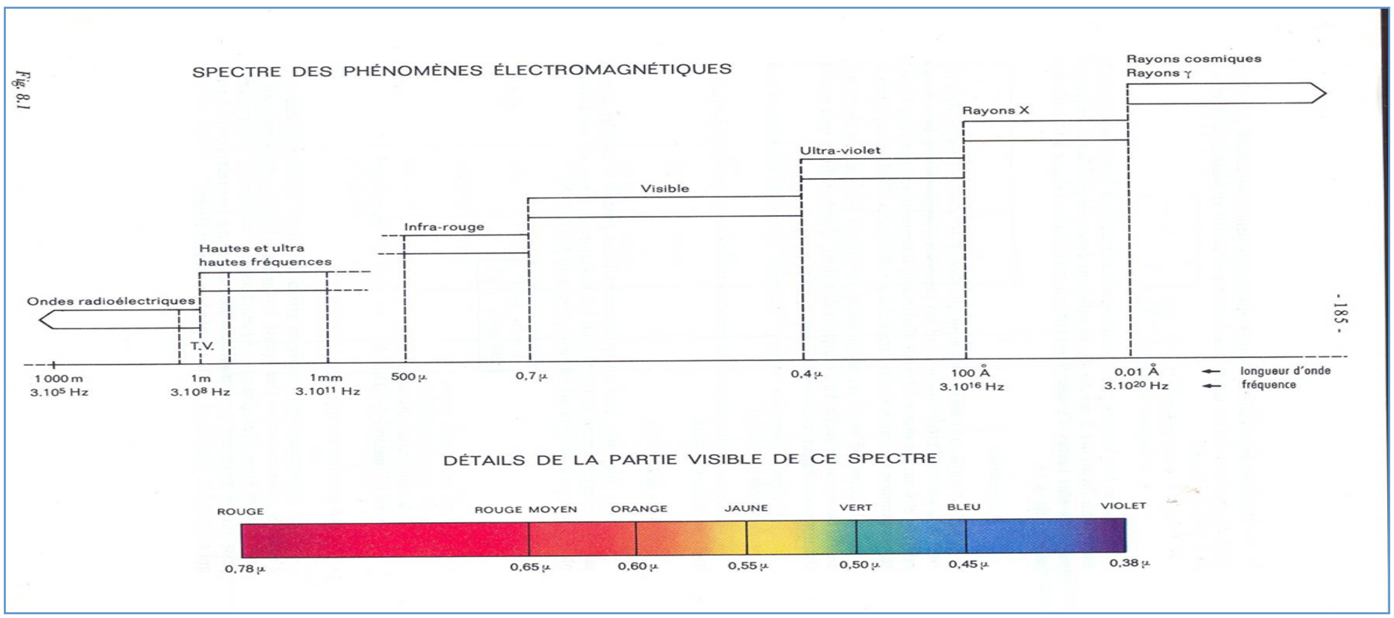
Maps of the TEC over Asia



Amory-Mazaudier et al, 2006

IONOSPHERIC DYNAMO

David Hysell



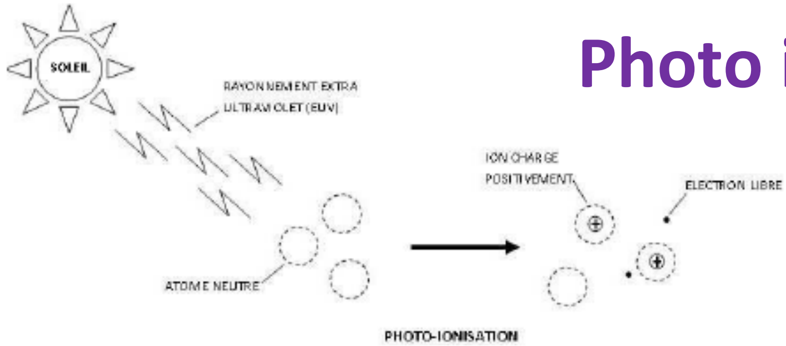
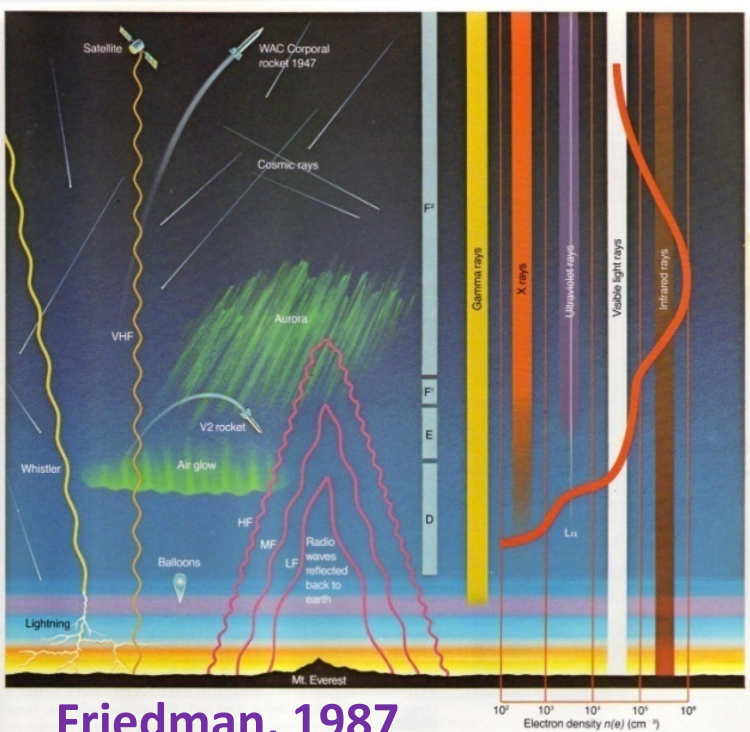


Photo ionisation

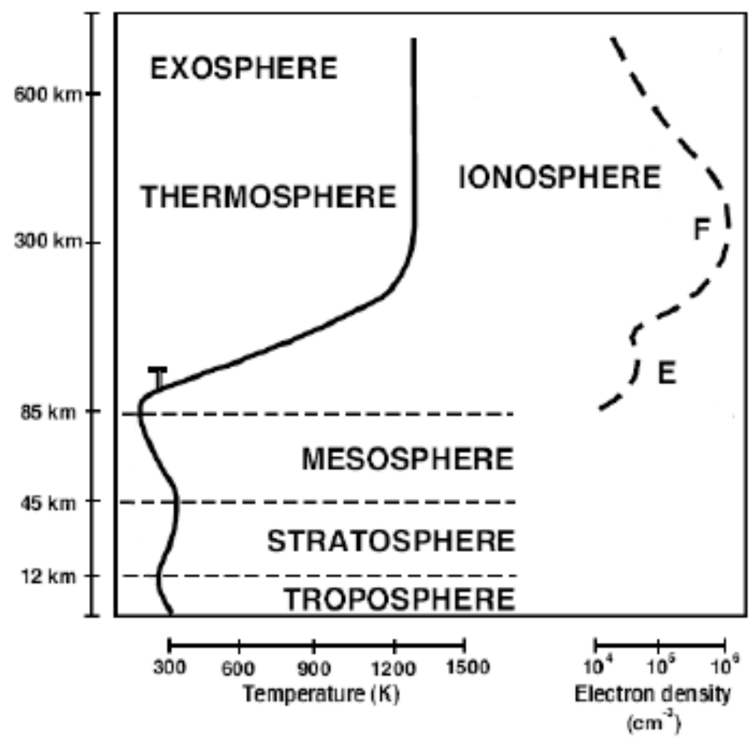
A -> A^{+} + e^{-}

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

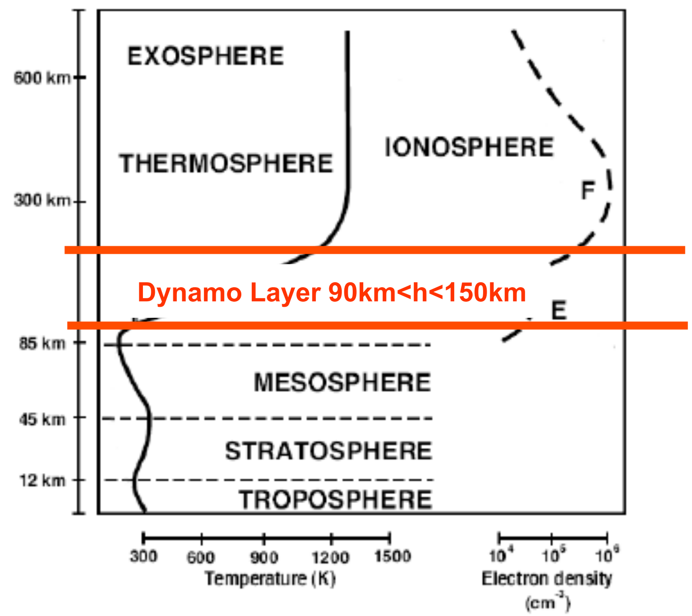
DYNAMO electric field | $V_n x B_t$ | E | POLARISATION electric field

IONOSPHERIC OHM'S LAW

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

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

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



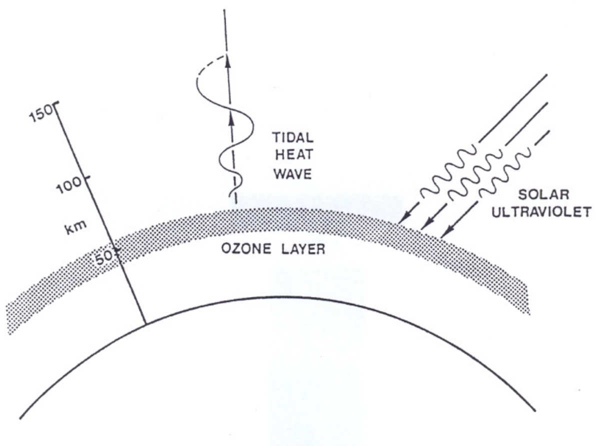
$$\Omega_e = \frac{eB}{m_e} \quad \Omega_i = \frac{eB}{m_i}$$

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

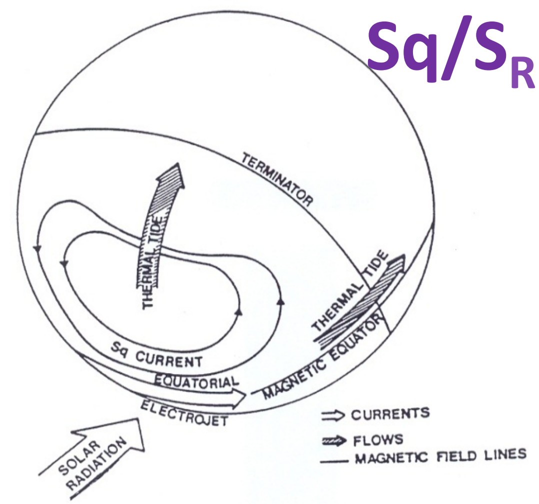
IONOSPHERIC DYNAMO / Neutral winds
John Meriwether

Stratosphere Atmospheric Tides , Evans 1977

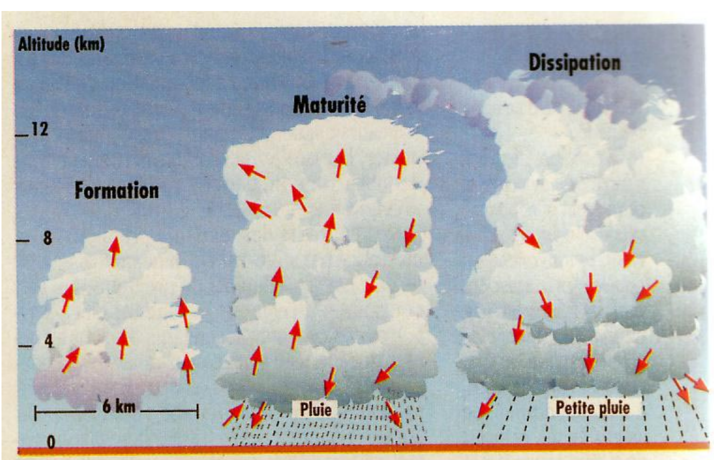


Diurnal process
E Region of the
Ionosphere
(90km< h< 150km)

Sq/S$_R$



Deep convection in the troposphere : non migrating tides

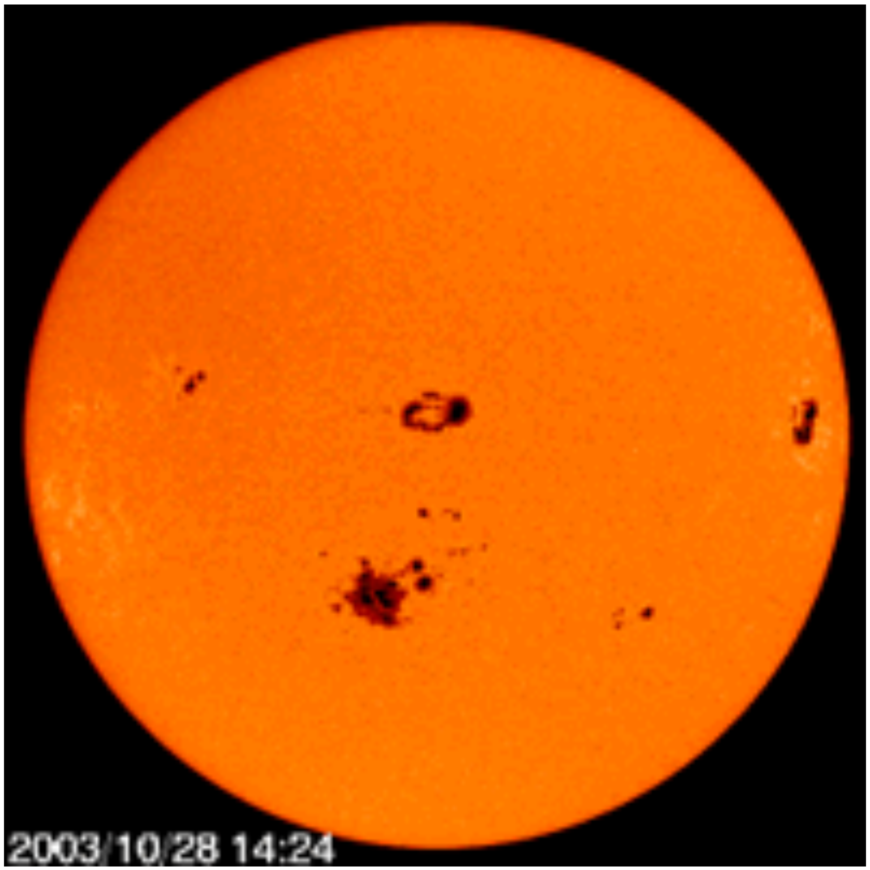


Vertical coupling
Stratosphere , troposphere
Atmospheric electricity
Earthquake, etc…

Field to investigate
Nikolai Ostgaard

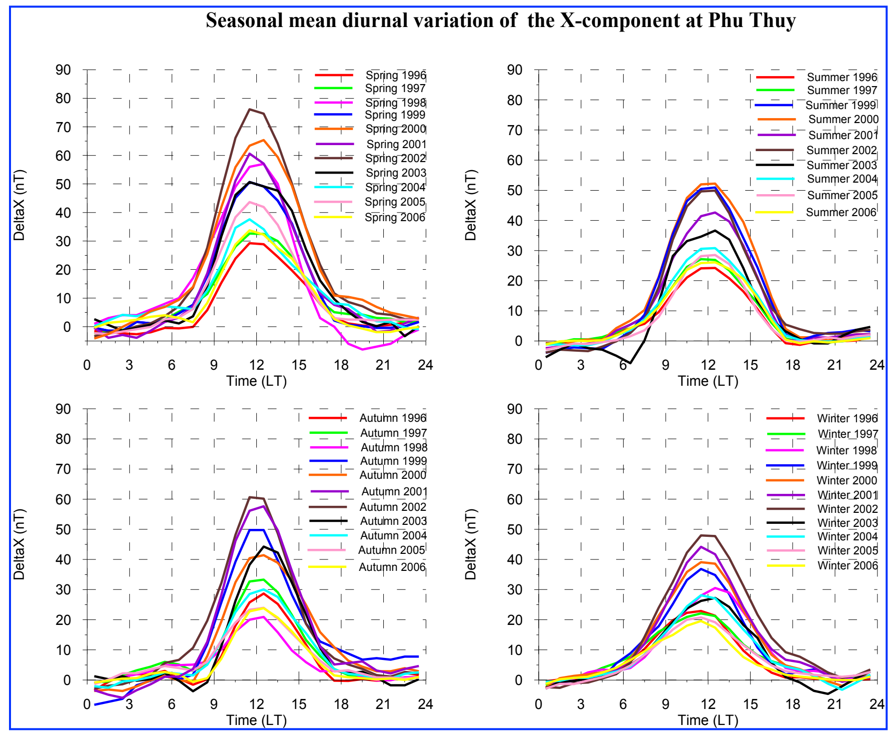
Sun Earth System

Sunspot
Solar Radiations EUV, UV



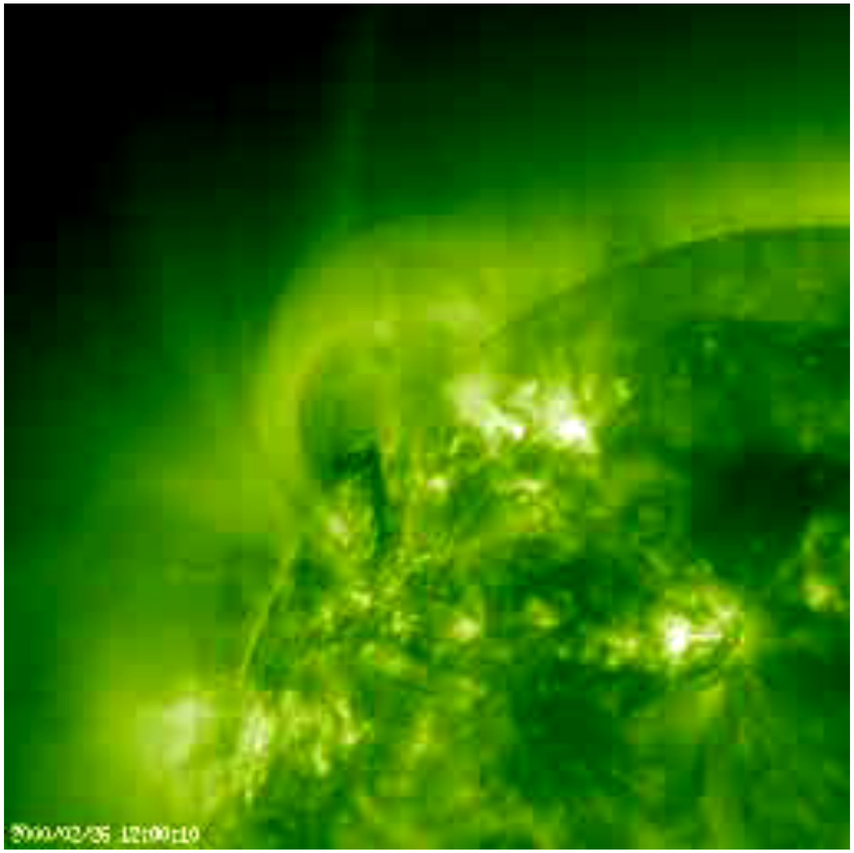
Images du satellite SOHO / NASA - ESA

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



Pham et al, Ann. Geophys. 2011

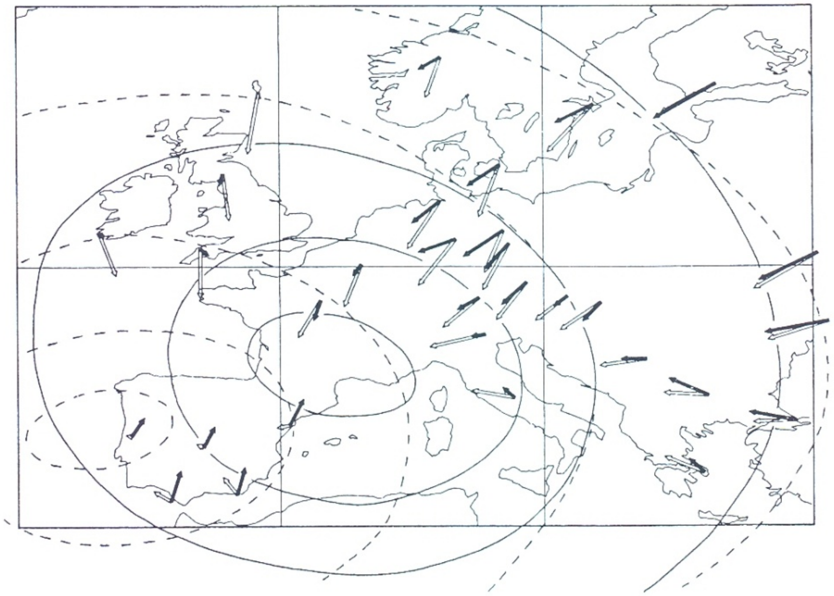
Solar flare (Nat Gopalswamy) affects directly the ionospheric dynamo



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

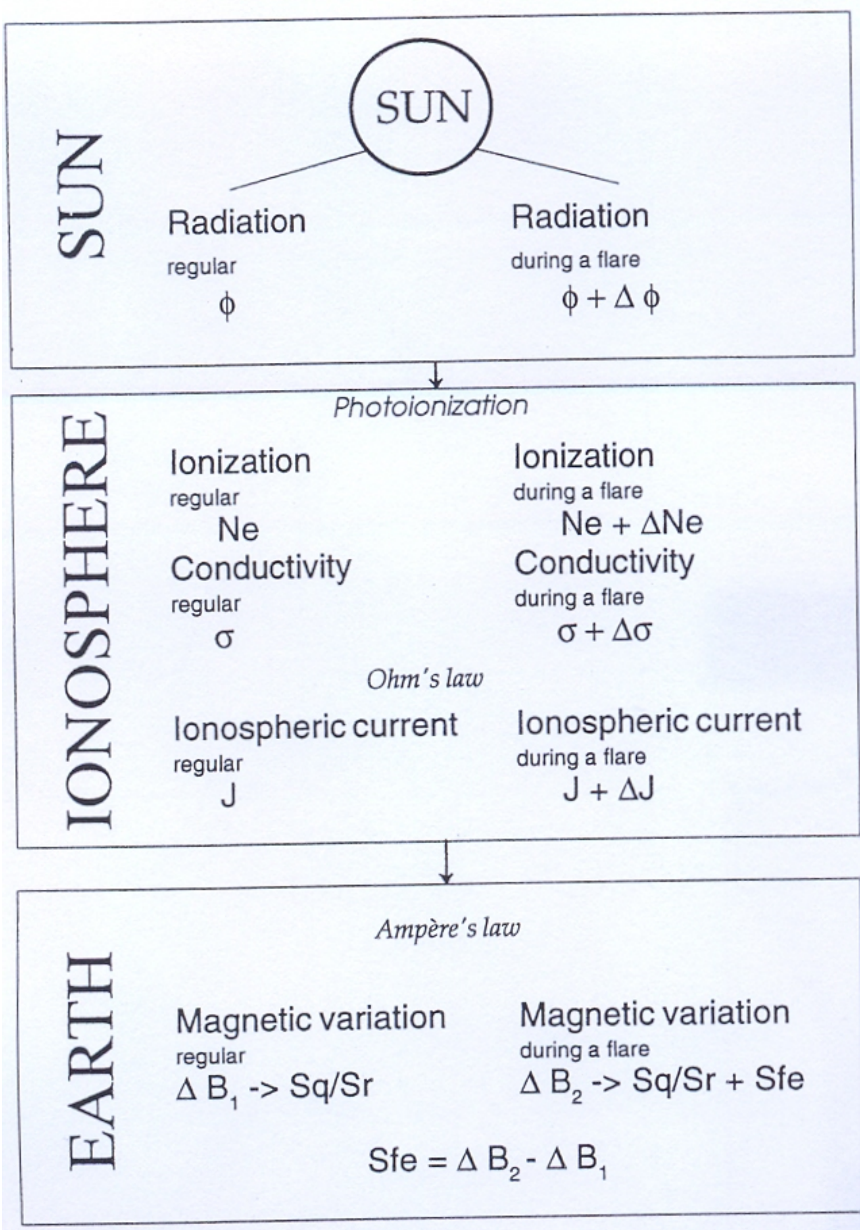
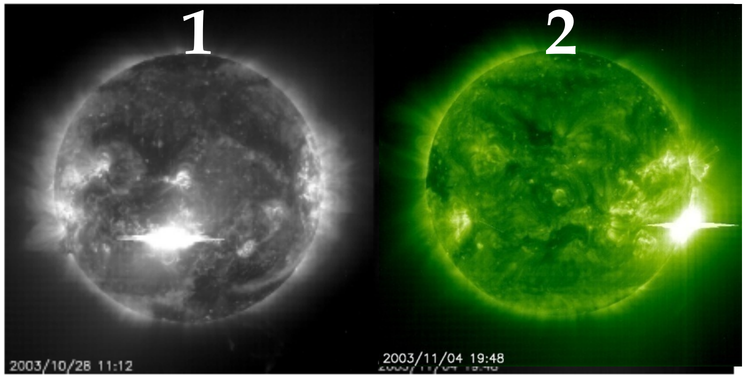


Table 1. Main Processes and Related Models Used.

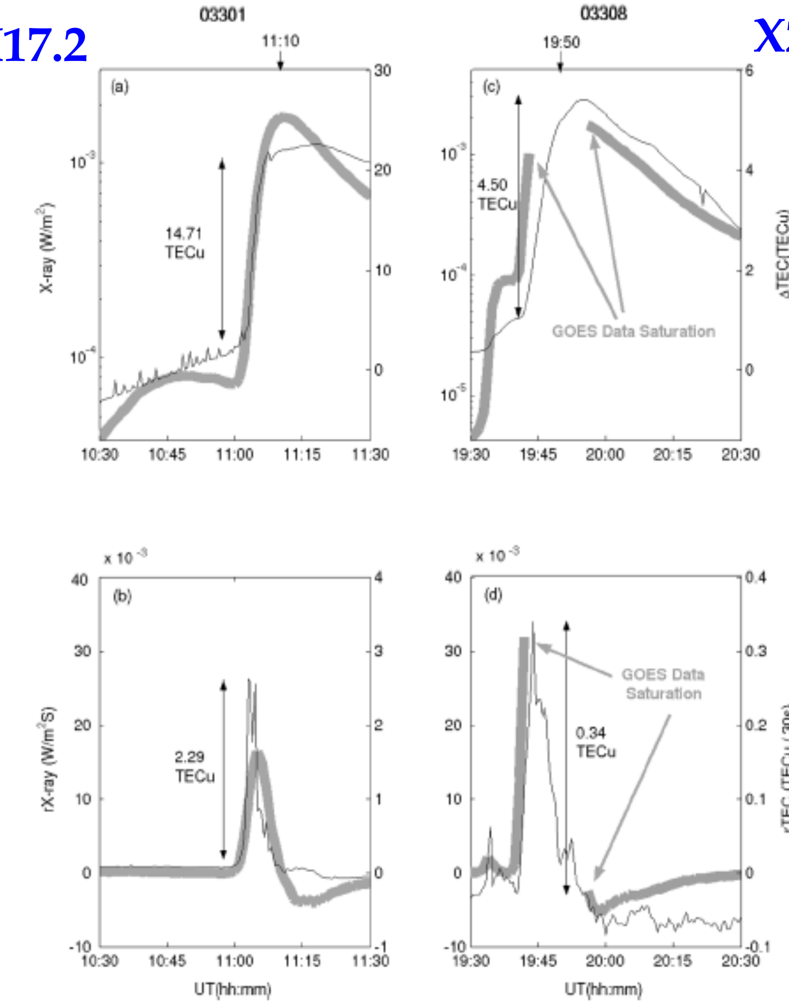
	Source
Sun Processes	
Models	
regular radiation flux	*Heroux et al.* [1974]
flare radiation flux	*Donnelly* [1976]
Ionosphere Processes	
Equations	
ion production rate	*Dymek* [1989]
continuity equation	*Dymek* [1989]
collision frequencies	*Stubbe* [1968]
Conductivity tensor (σ)	$\overline{\overline{\sigma}} = \begin{pmatrix} \sigma_P & \sigma_H & 0 \\ -\sigma_H & \sigma_P & 0 \\ 0 & 0 & \sigma_{//} \end{pmatrix}$
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	$\Delta B = 2\pi/ 10f \int jdz$



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

X17.2 X28



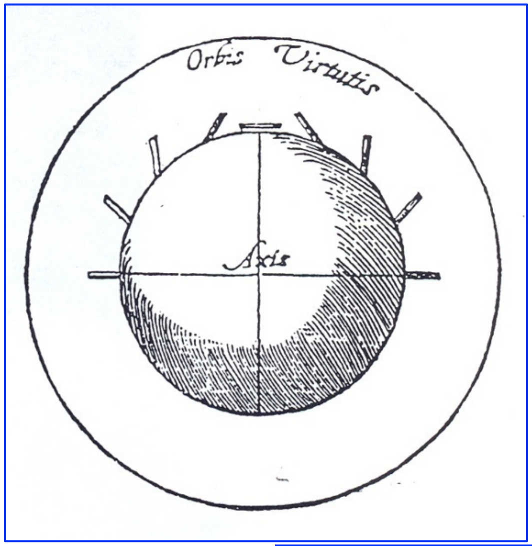
SOLAR FLARES AFFECT TEC

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

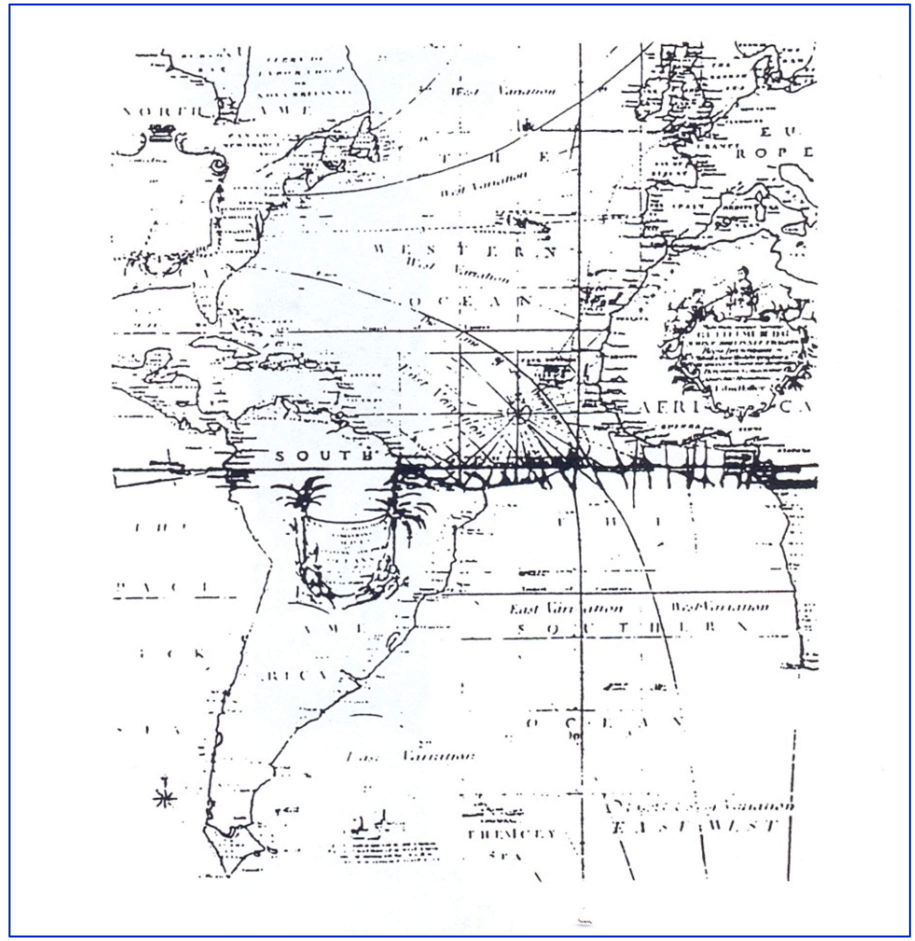
To analyze the ionospheric dynamo , it is necessary to select carefully   the magnetic quiet days

Earth’s Dynamo

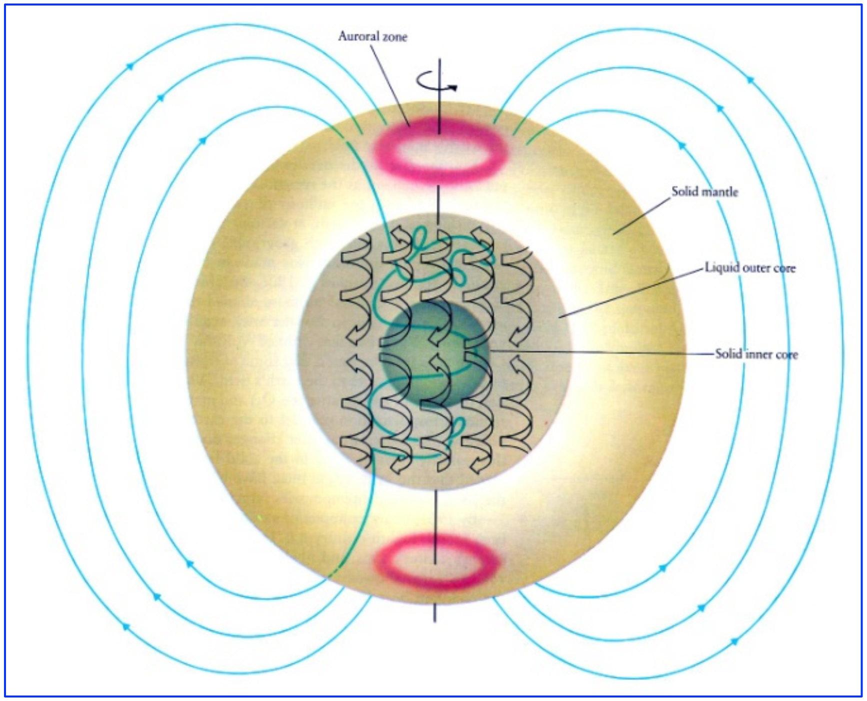
EARTH'S DYNAMO
Earth's magnetic field known since more 2 millenaries



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

First exercice : Solar Dynamo
Sun and solar events

- Period 1-31 August 2010

- 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											

Nat Gopalswamy

Second exercice :
Solar wind –magnetosphere dynamo

Period 1-31 August 2010

OMNIWEB data base
SPIDR data base

Summary

Earth's motions

Definition of Space Weather

Sun Earth Links through dynamo processes : the main permanent dynamos

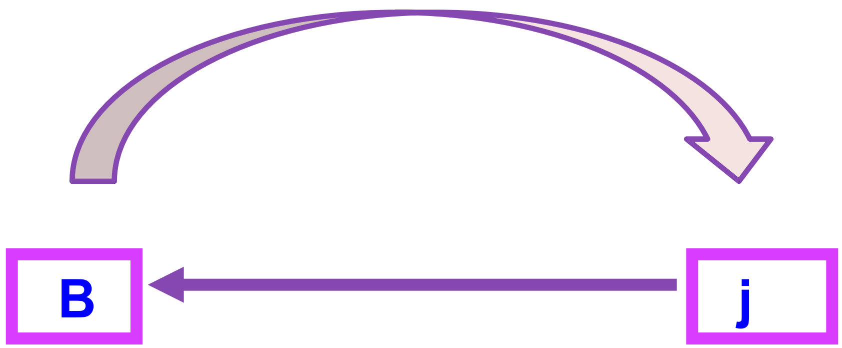
- Solar dynamo
- Solar wind/magnetosphere dynamo
- Ionospheric dynamo
- Earth's dynamo

Electric current systems

62

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

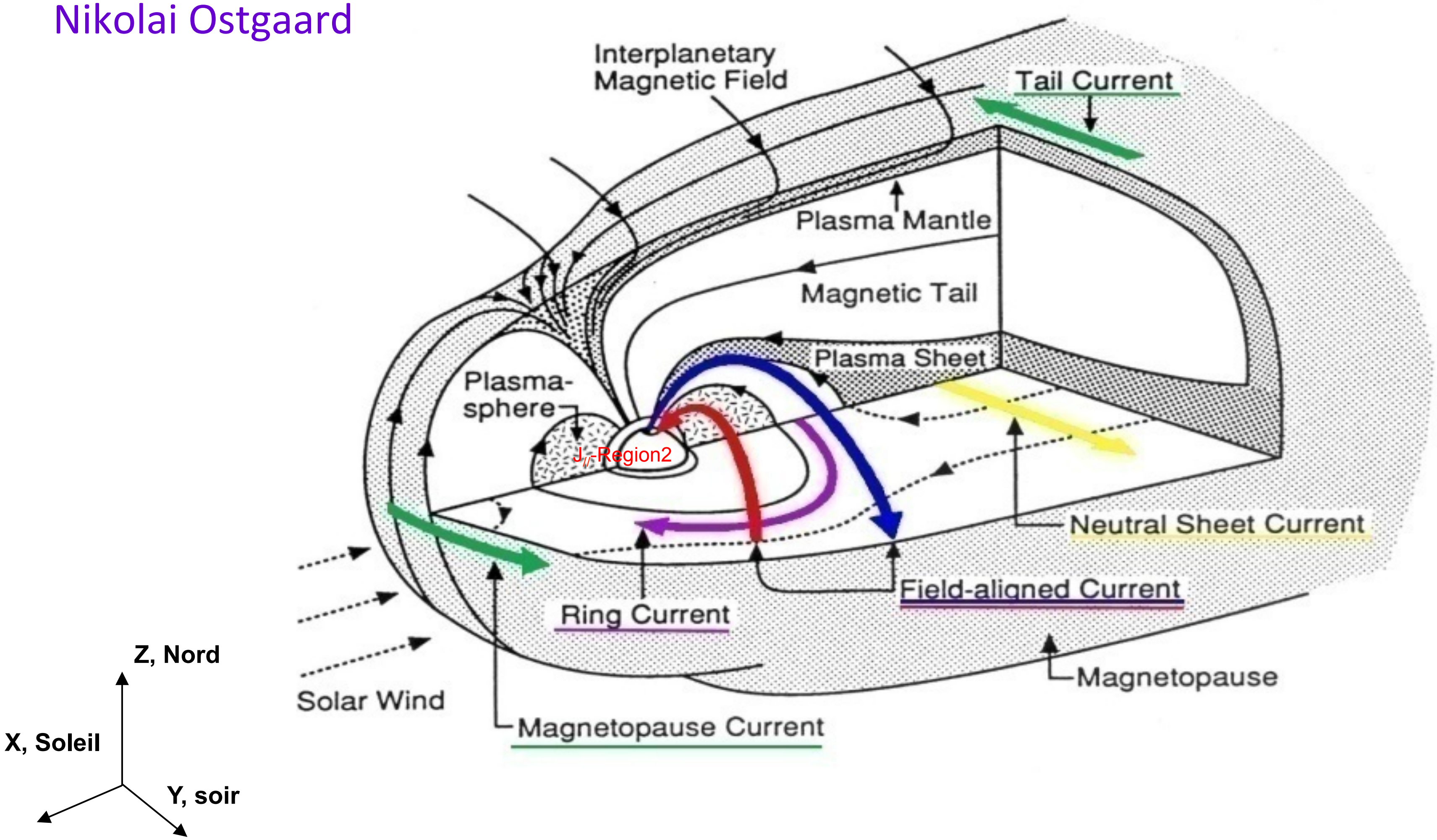
$\nabla \times B = \mu j$

OHM'S LAW

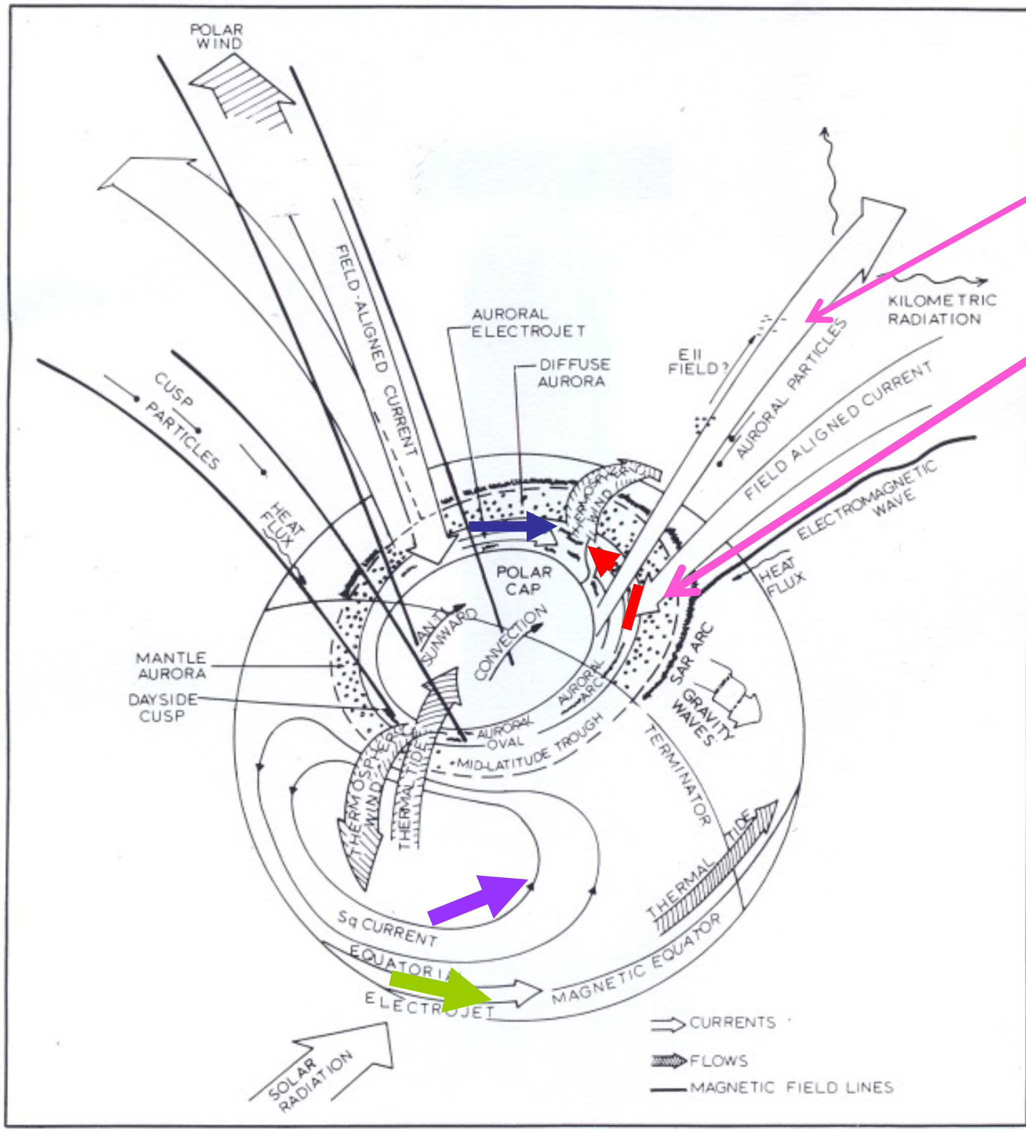
$j = \sigma (E + V \times B)$

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

Nikolai Ostgaard



Ionospheric electric currents related to the solar wind magnetosphere dynamo and Ionospheric dynamo



Field aligned current

Auroral electrojets

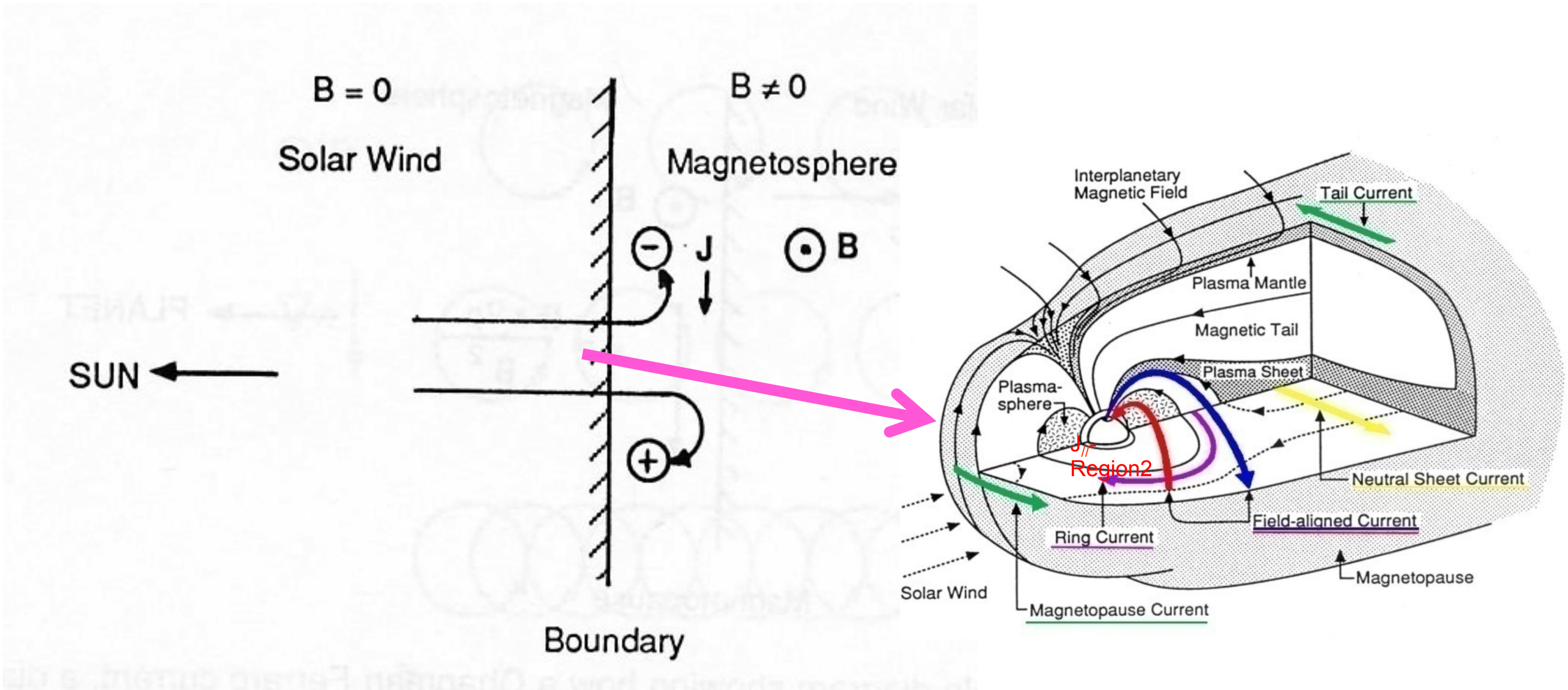
Precipitation of particles

Electric field

Auroral

Middle latitudes

Equatorial latitudes

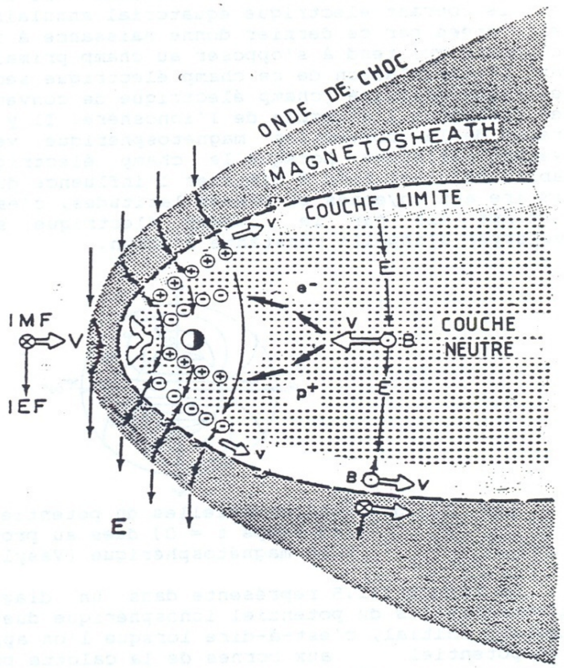


The Chapman Ferraro currents flow in the Magnetopause layer, the boundary between the solar wind and the geomagnetic field. At the nose of the magnetopause the geomagnetic field pressure is balanced by the dynamic pressure of the solar wind

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

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 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.

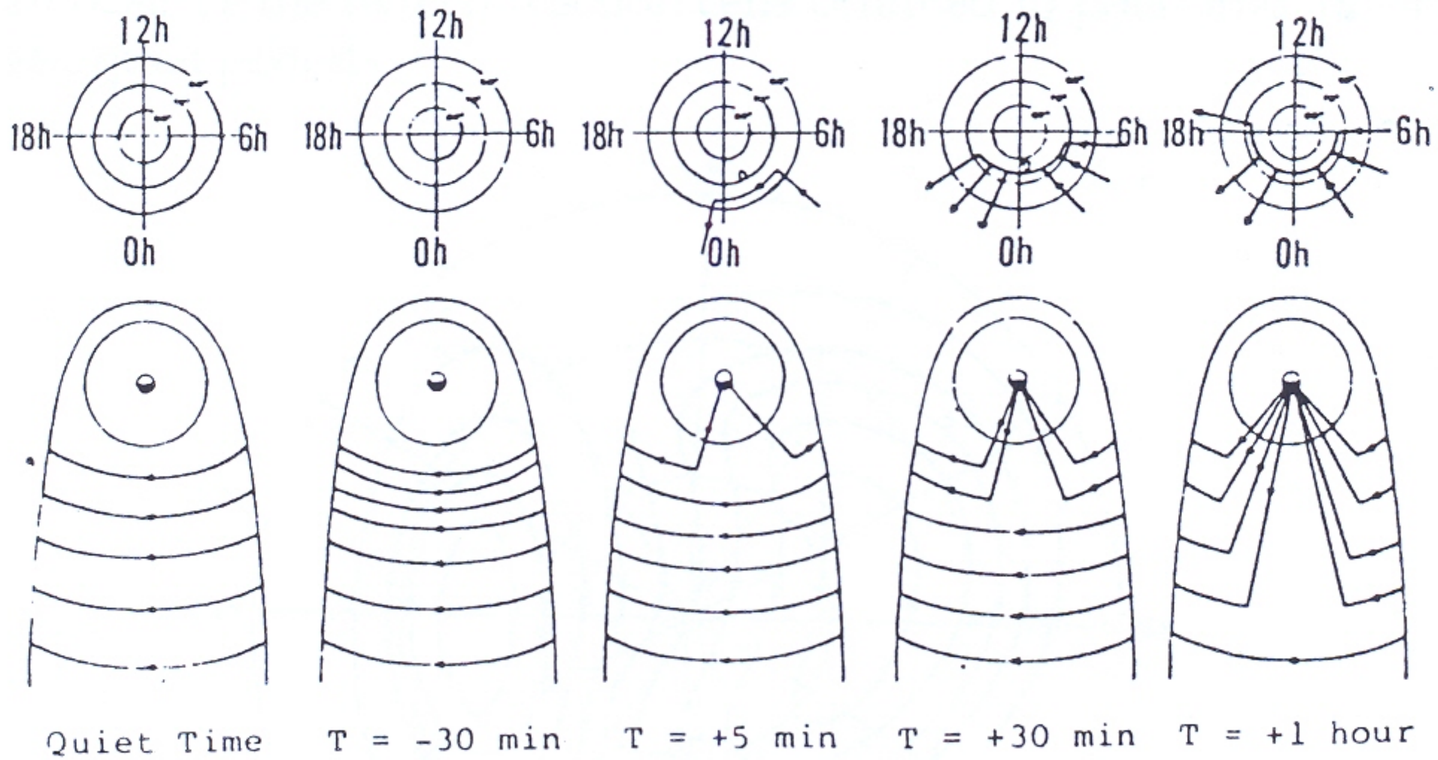
There is also an additional contribution of the magnetic moments of all particles:

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

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

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

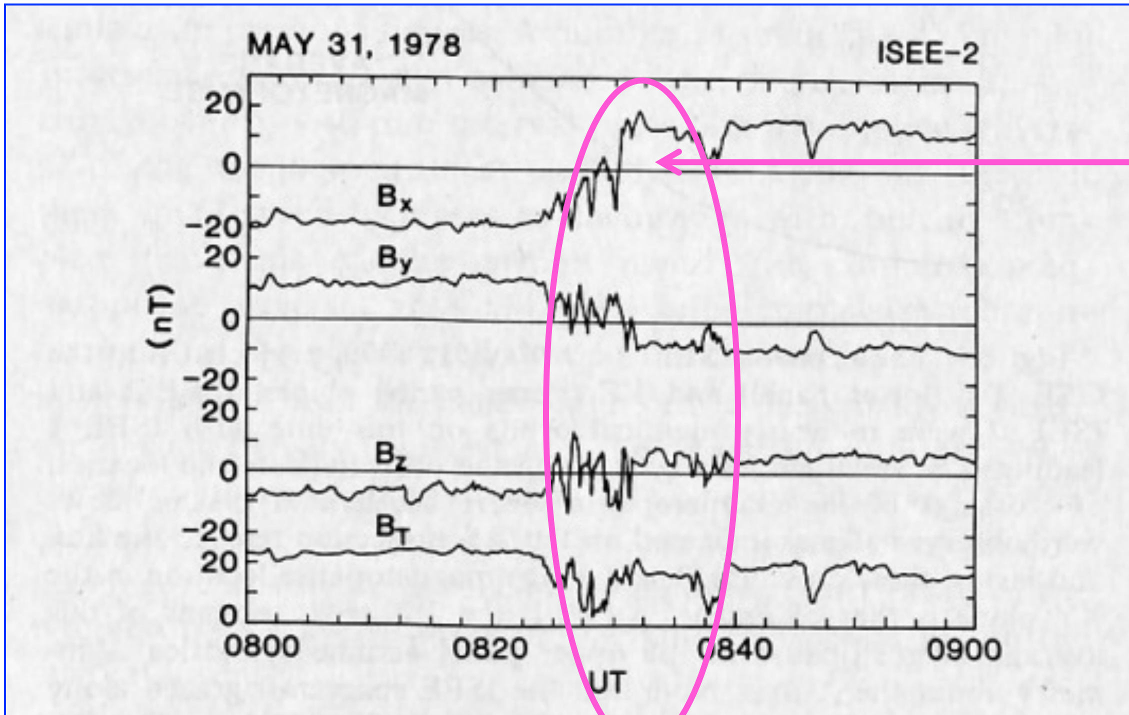
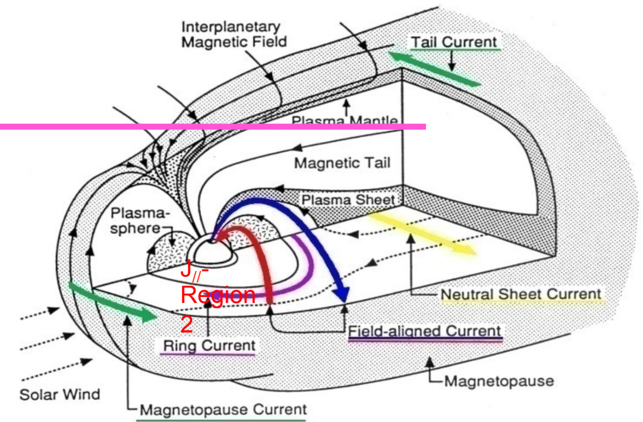
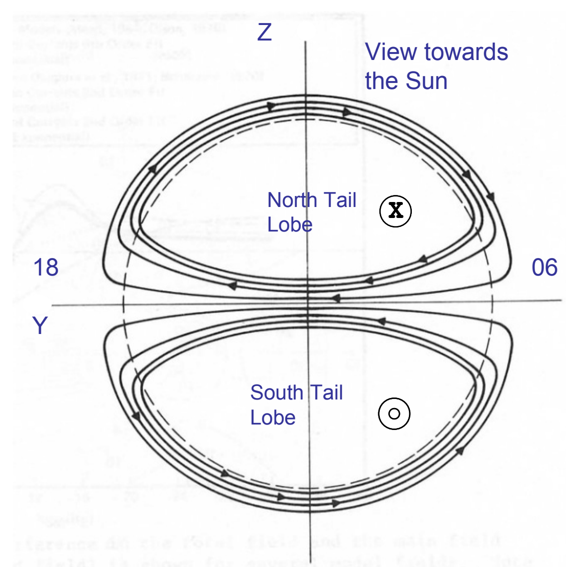


Fig. 2. Magnetic field data from ISEE 2 surrounding the ~0830 UT magnetopause crossing on May 31, 1978. From top to bottom the quantities plotted are the *x*, *y*, and *z* components (GSE coordinates) of the field and the total field magnitude.

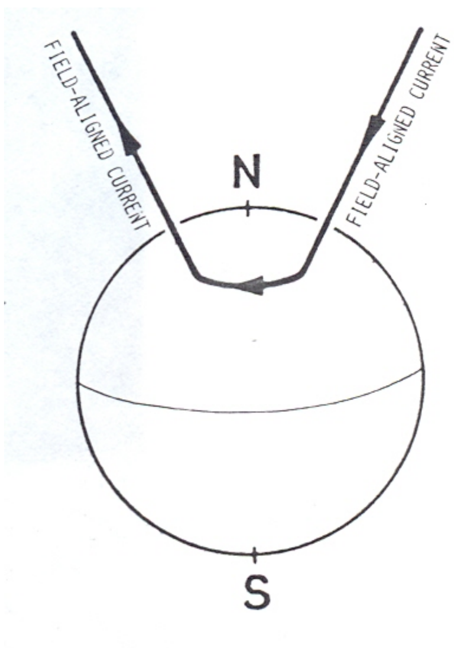




crossing of the magnetopause

Field aligned currents/1908

Birkeland, 1908



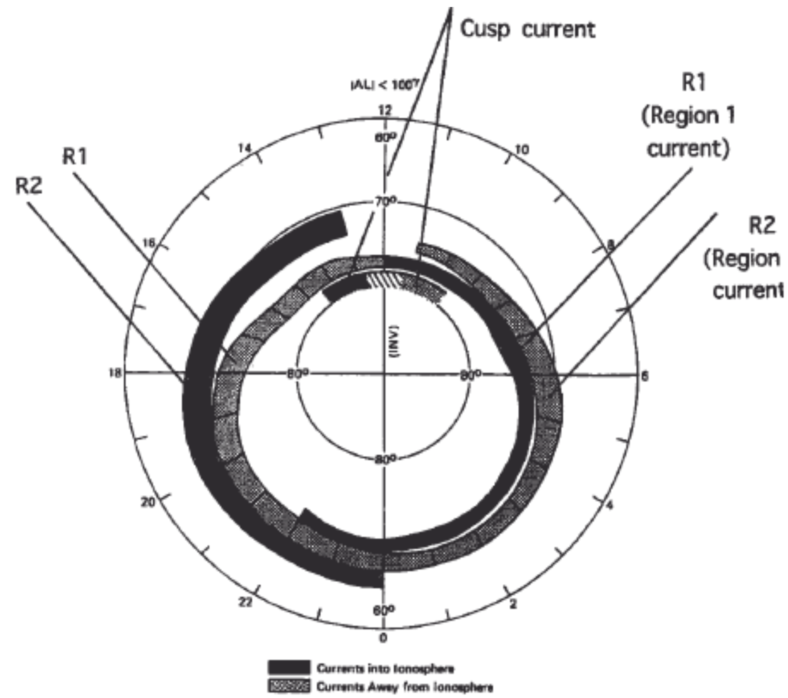
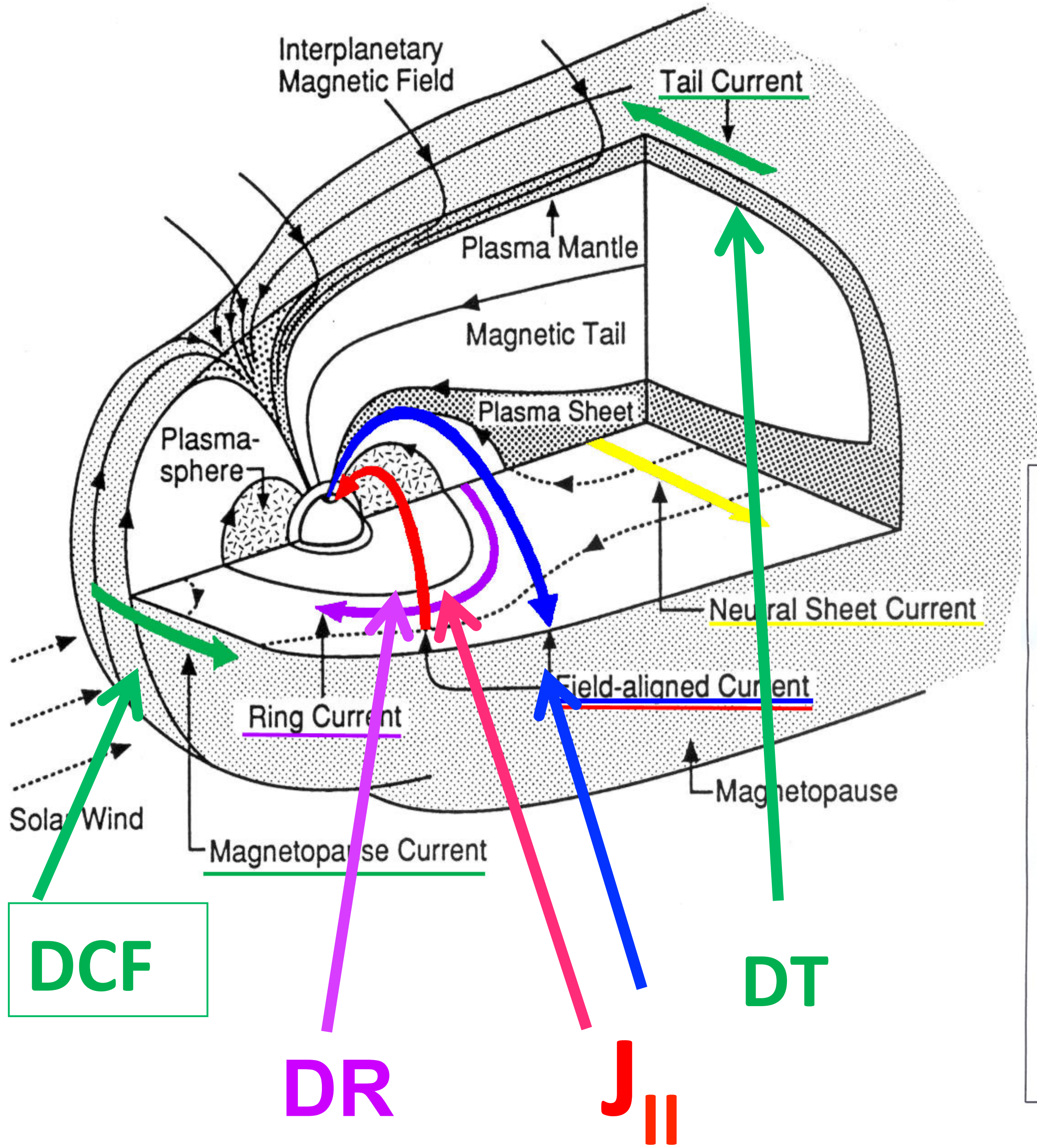
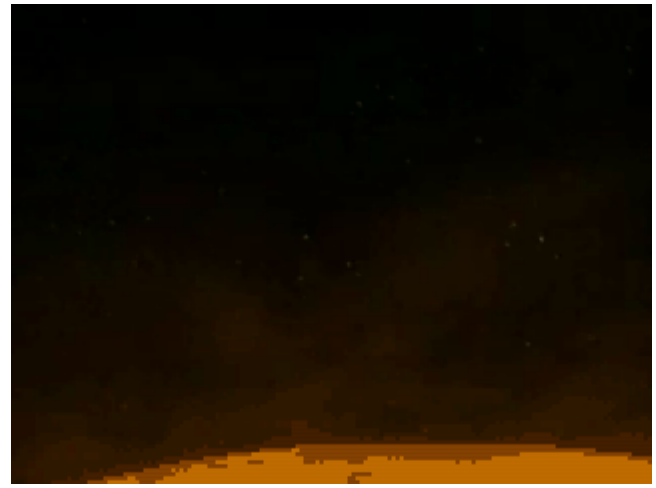


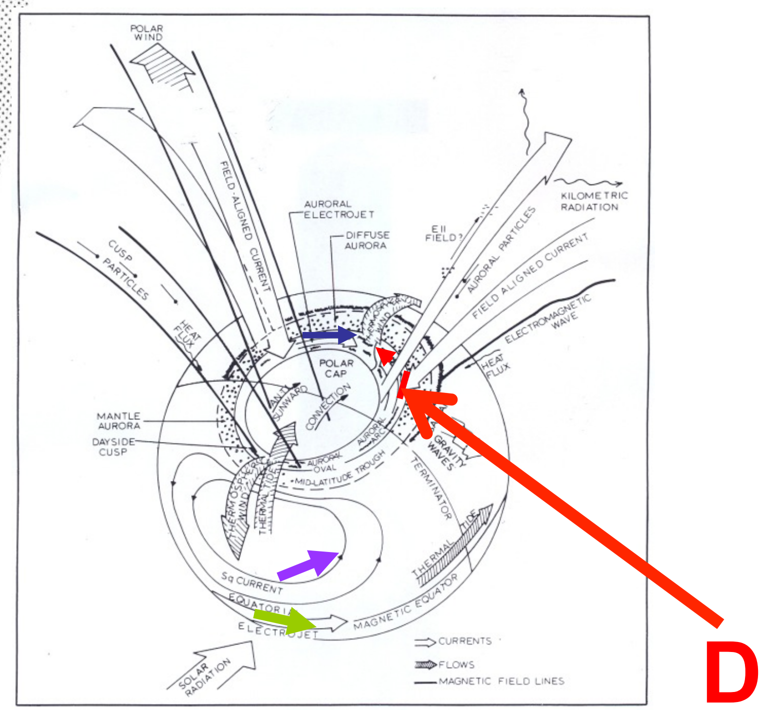
Figure 2.4 Pattern of field-aligned currents derived by Triad data (Iijims and Potemra, 1976a).

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

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.


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_{II}
DT




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

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

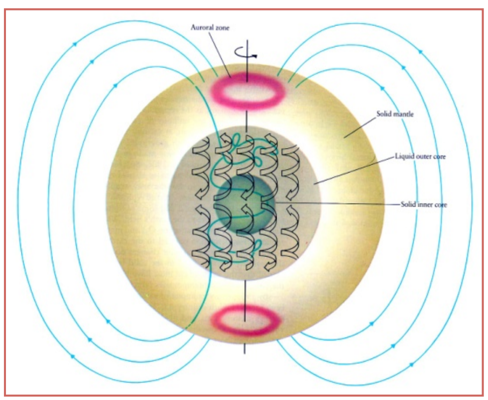
4 DYNAMOS IN

SUN
poloidal /toroidal

MAGNETOSPHERE
Solar wind
IMF

IONOSPHERE
Earth's magnetic field
Neutral wind

EARTH
Motions of the core

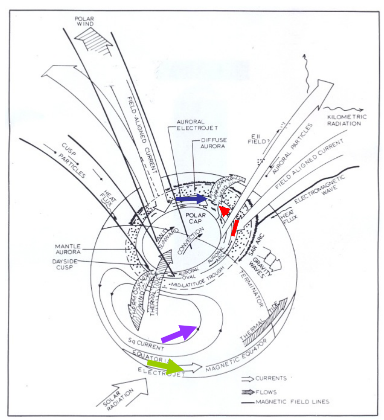


CURRENT SYSTEMS

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