The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

310/1749-38

ICTP-COST-USNSWP-CAWSES-INAF-INFN
International Advanced School
on
Space Weather
2-19 May 2006

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# *Solar Drivers of Geoeffective Phenomena and their Precursors*

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*SWEDEN*



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# The Sun: Space Weather Applications

## 3) Solar drivers of geoeffective phenomena, and their precursors

## ICTP-COST-CAWSES-INAF-INFN, Trieste, 2006

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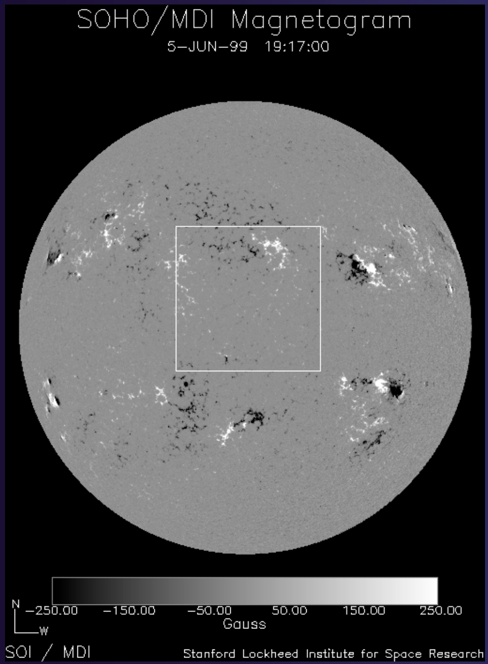
COST 724

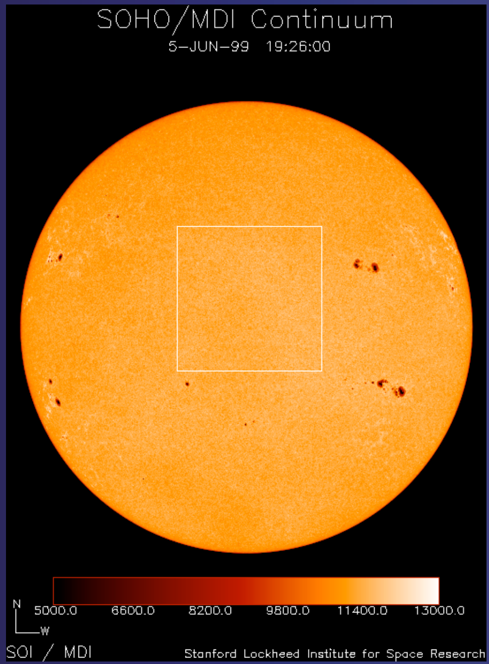
CAWSES
Climate and Weather of the Sun-Earth System
The New SCOSTEP Program for 2004-2008

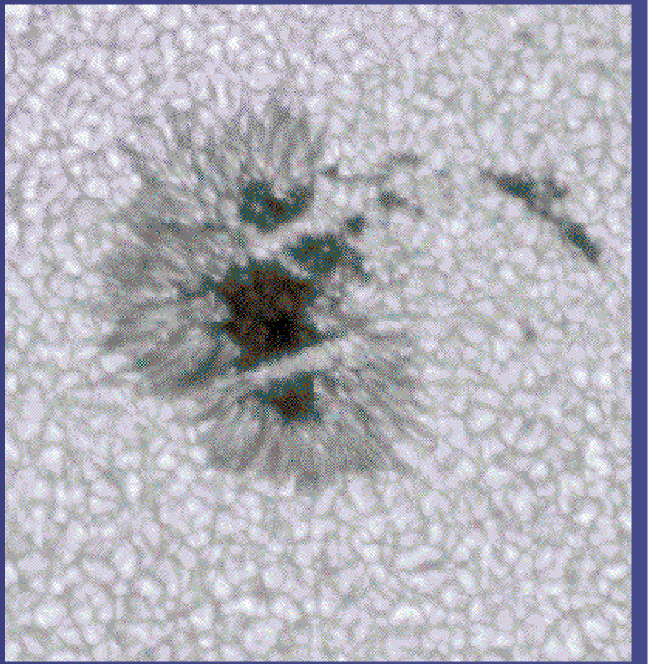
# Outline of my third talk

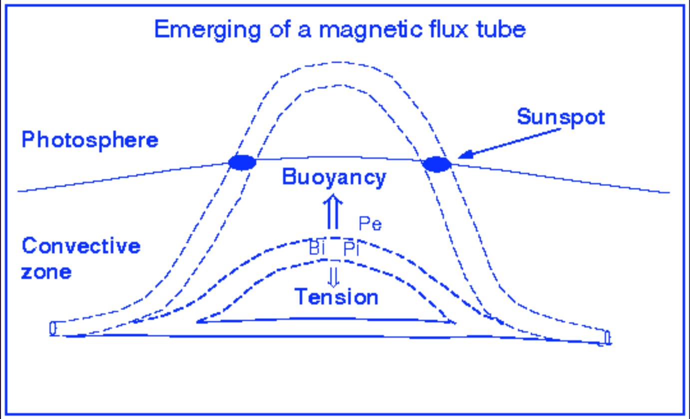
- Solar drivers
- Space weather effects
- Precursors (CMEs/flares, fast solar wind/HSCS)
  - Appearance of large spots/ARs on solar center
  - Disappearing filaments/CME
  - The AR's magnetic complexity
  - Activity below solar surface and farside activity

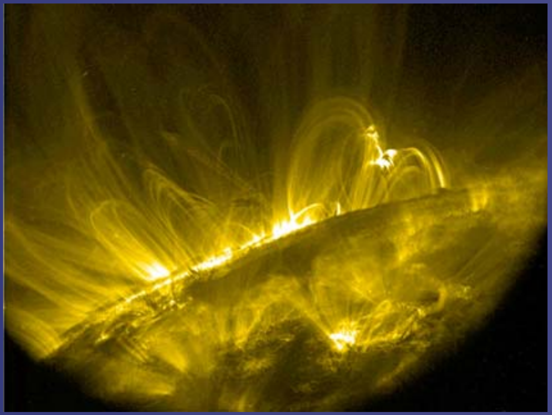
# When the solar magnetic field emerges thru the solar suface sunspots appear



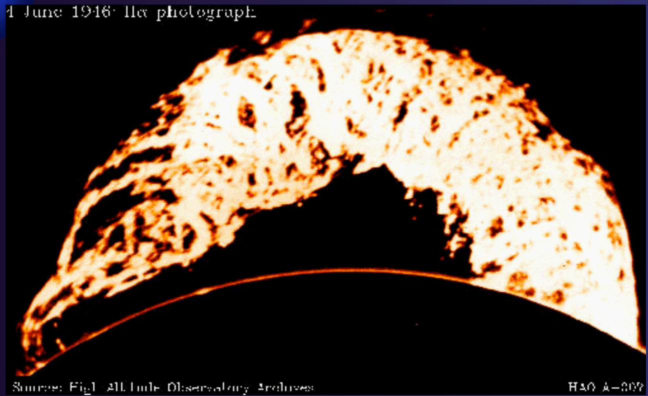



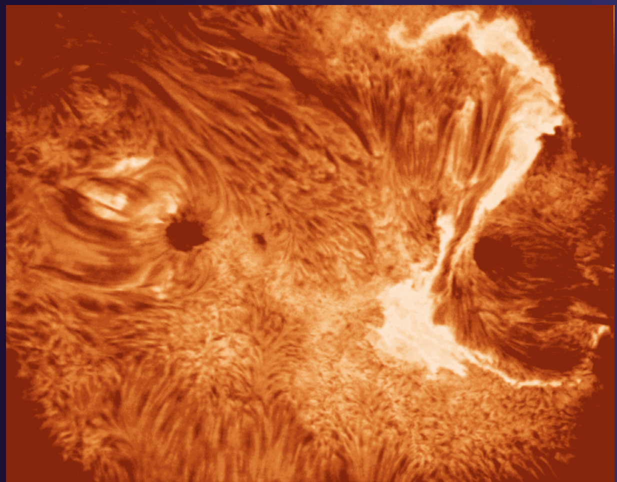


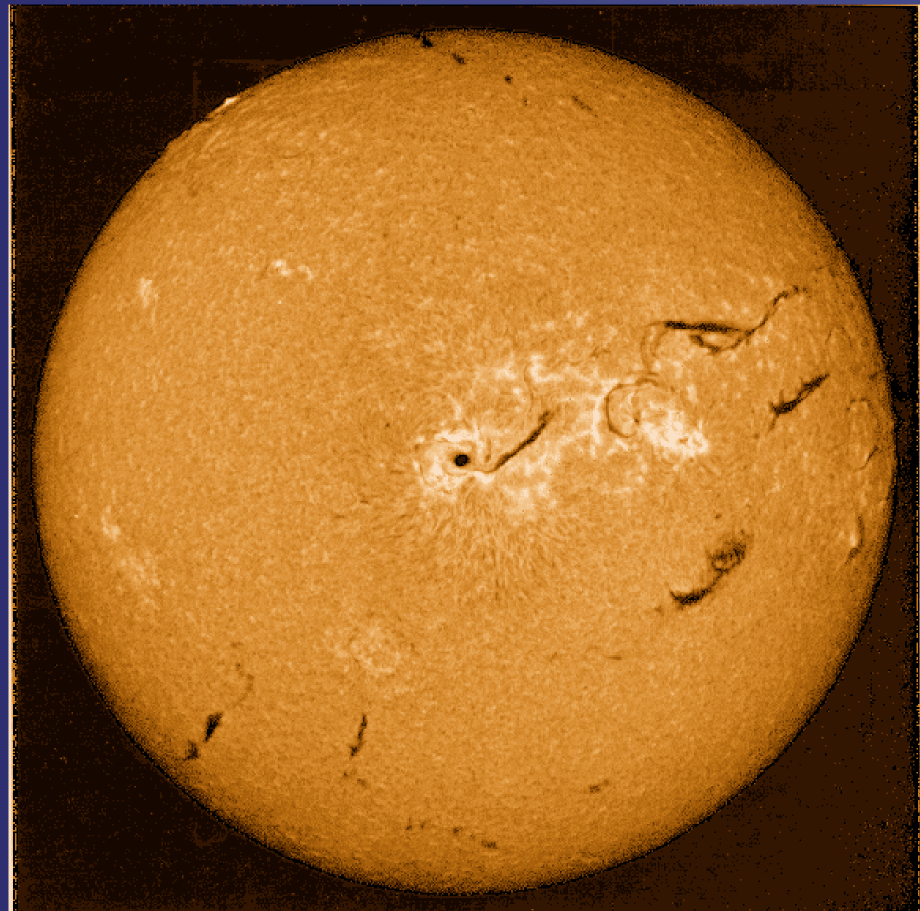
# Chromosphere




Prominence

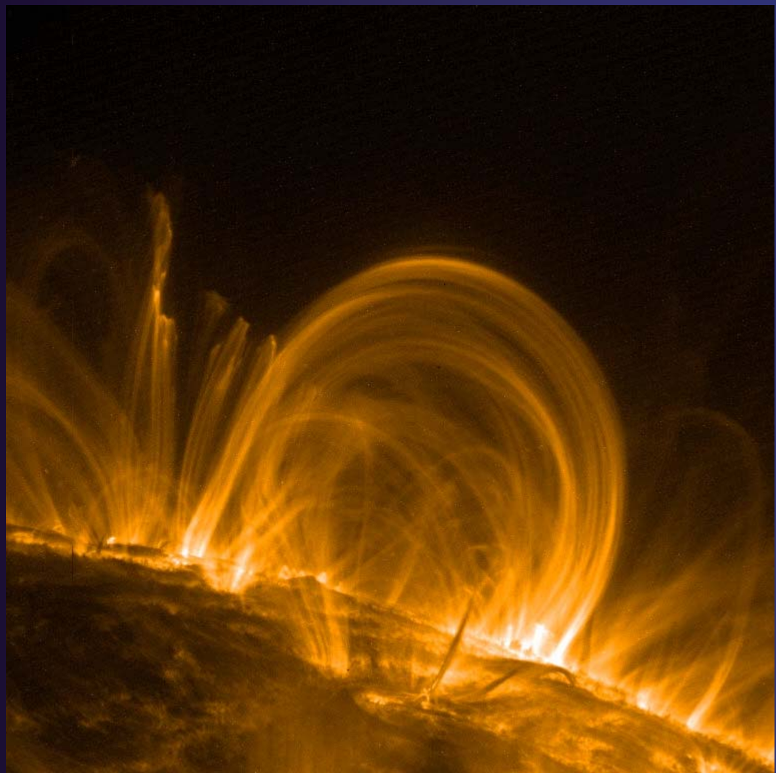


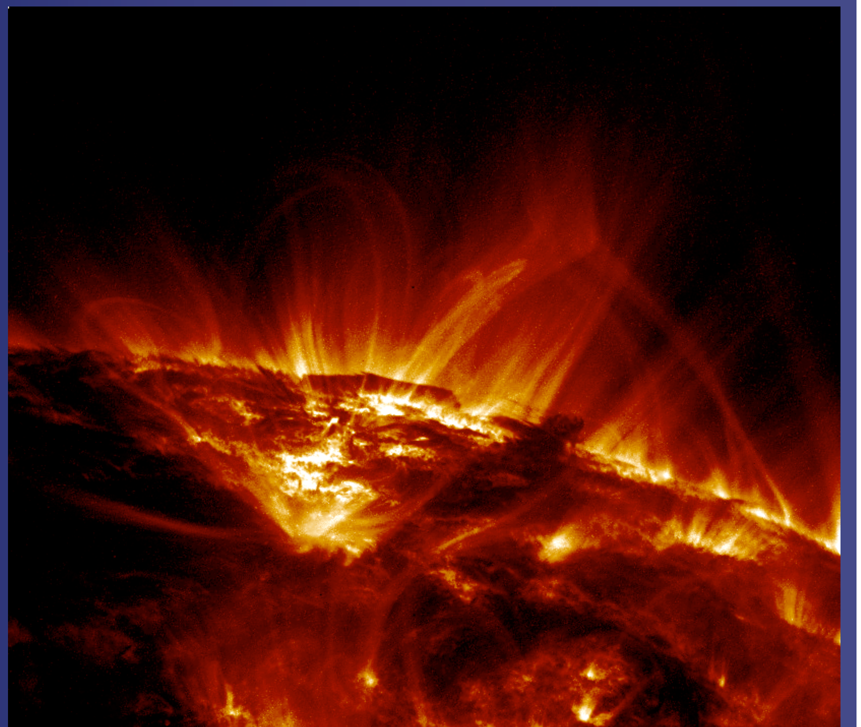
Solar flare



The chromosphere in H-alpha

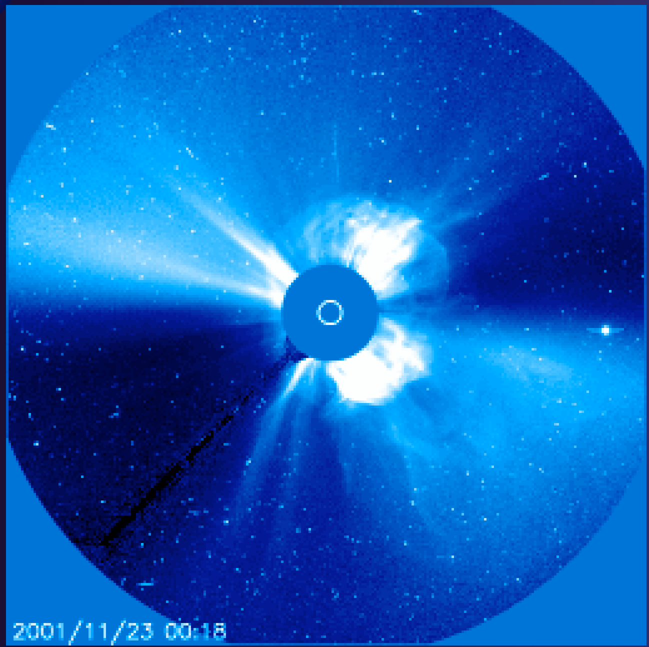
# TRACE

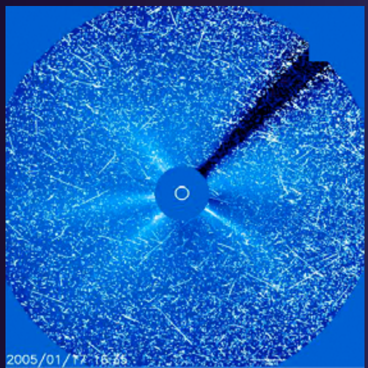




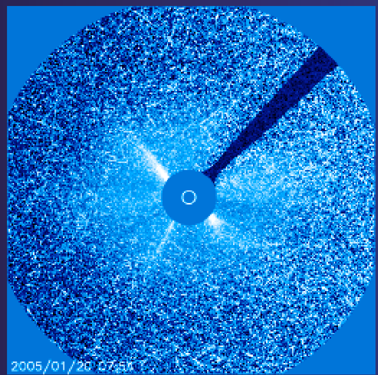
# Coronal mass ejections

# CMEs cause the most severe space weather effects



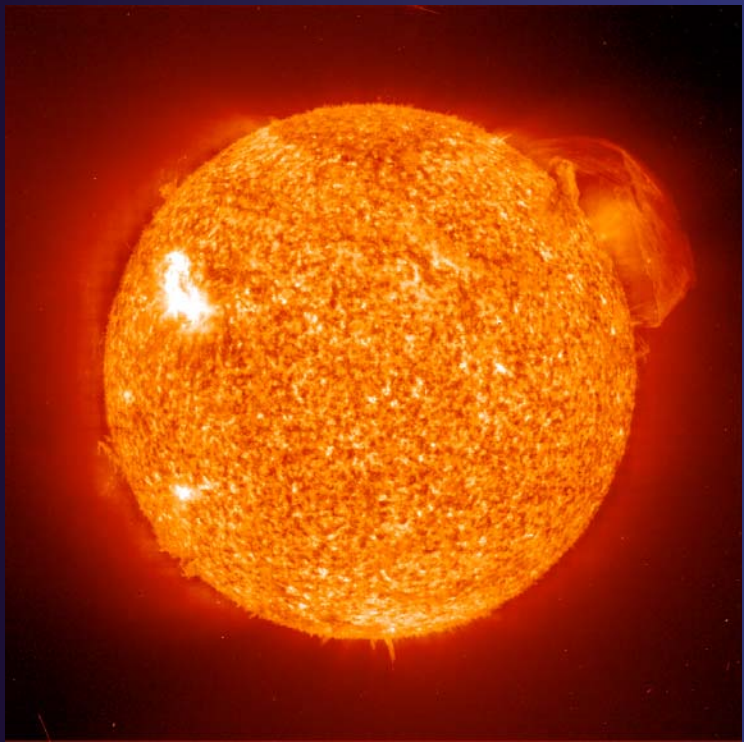
17 Jan. 2005

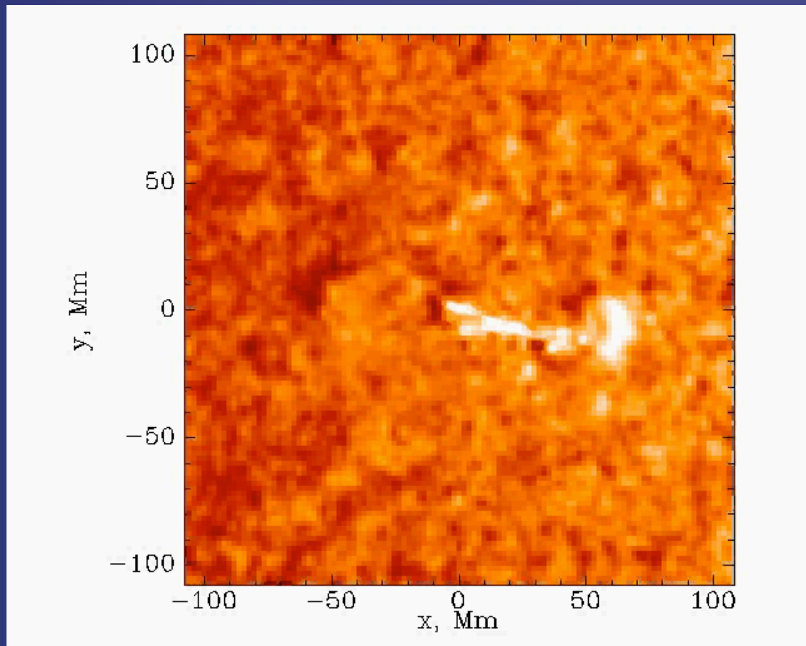


20 Jan. 2005

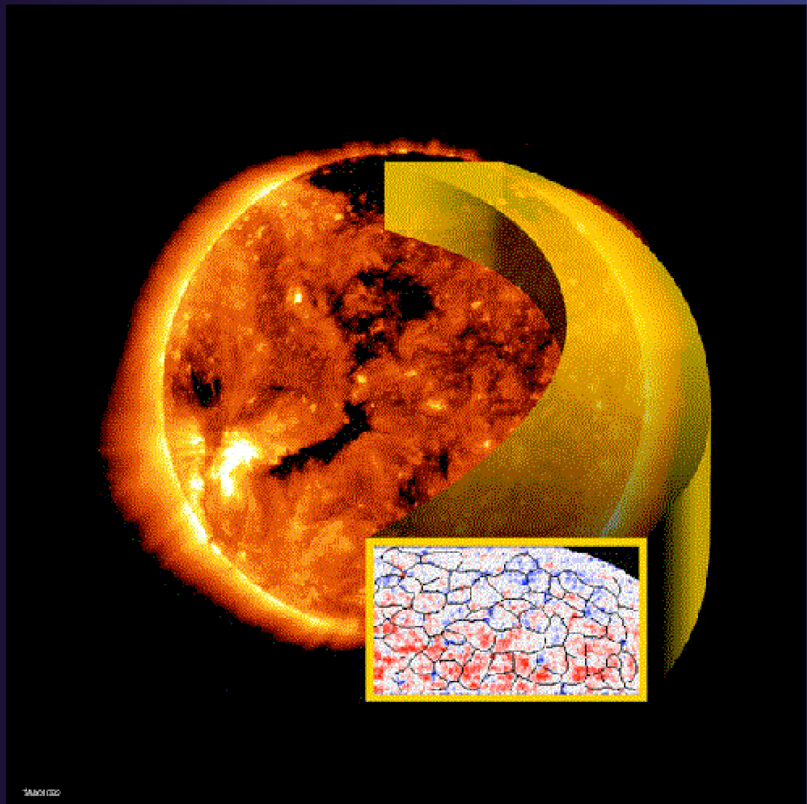
- Halo CMEs are most geoeffective
- Mass: 5-50 billion tons
- Frequency: 3.5/day (max), 0.2/day (min)
- Speed: 200-2000 km/s

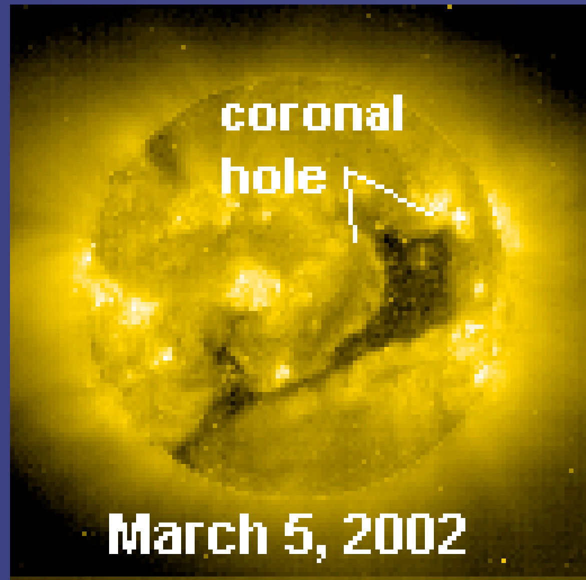
# Solar flares and sun quakes

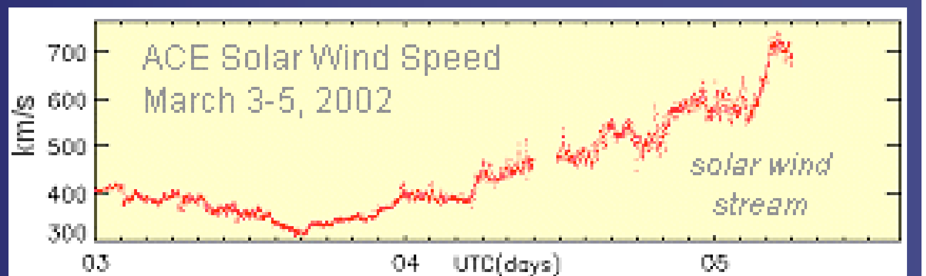




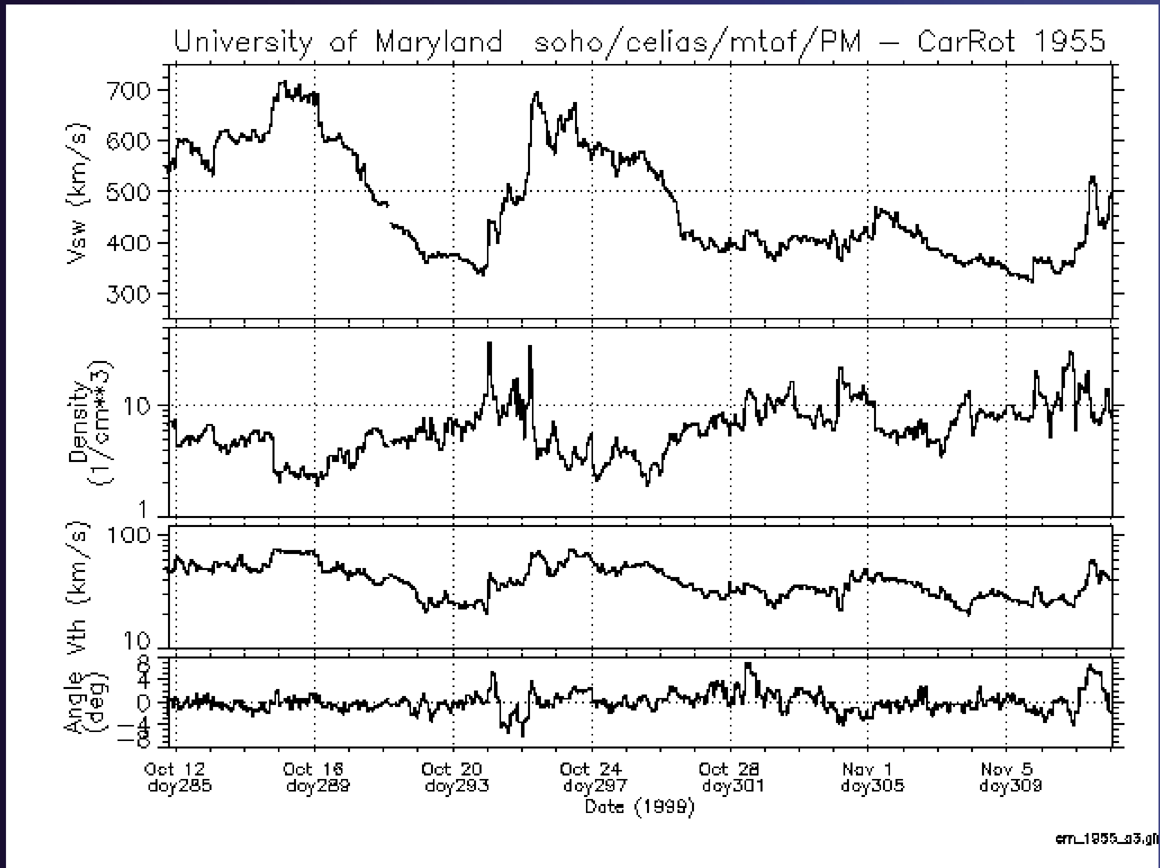
# The source of the fast solar wind





# Solar wind

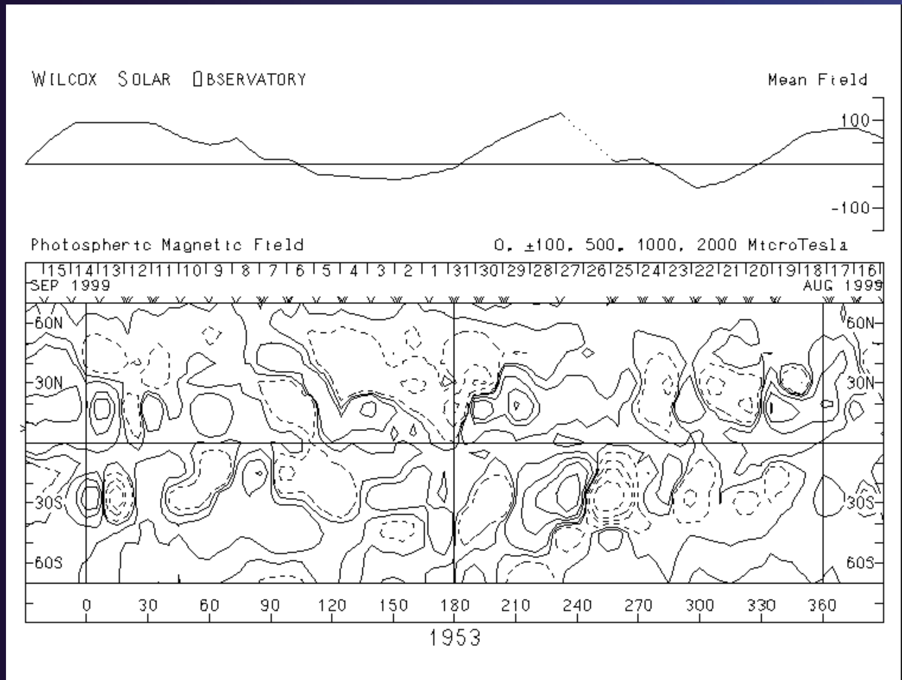



Typical values

V: 450km/s
N: 5particles/cm$^3$
T: $10^5$ K
B: 5nT

The solar wind consists
of protons,
electrons and
3-4% alpha
particles

# Computation of the coronal magnetic field




Daily observations of the solar photospheric magnetic field at WSO are used for computation of the coronal magnetic field according to the ”potential field model”.

$$\nabla \times B = 0, B = -\nabla\psi$$

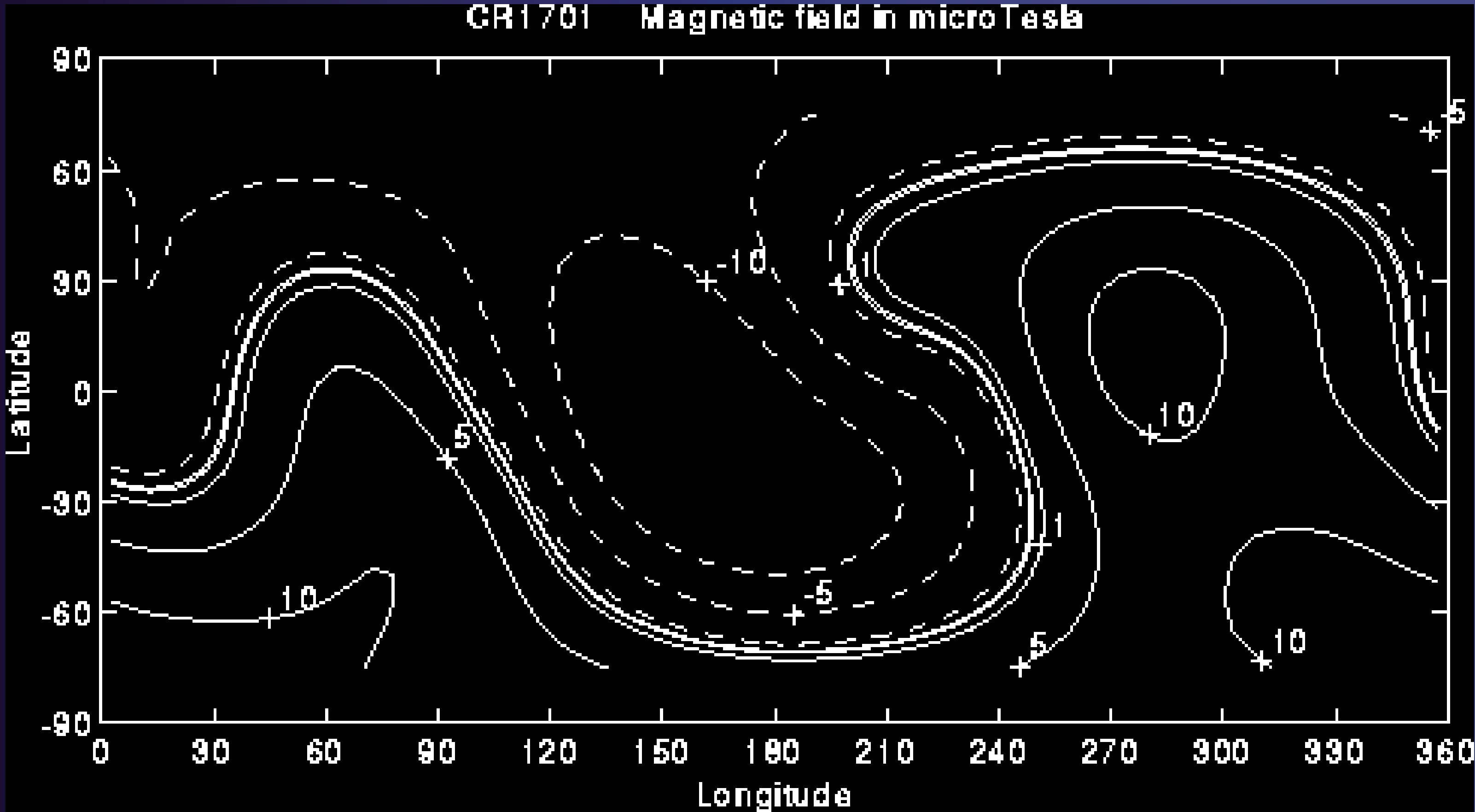
$$\nabla \bullet B = 0, \nabla^2\psi = 0$$

$$B_r = -\frac{\partial\psi}{\partial r}, B_\theta = -\frac{1}{r}\frac{\partial\psi}{\partial\theta}, B_\phi = -\frac{1}{r\sin\theta}\frac{\partial\psi}{\partial\phi}$$

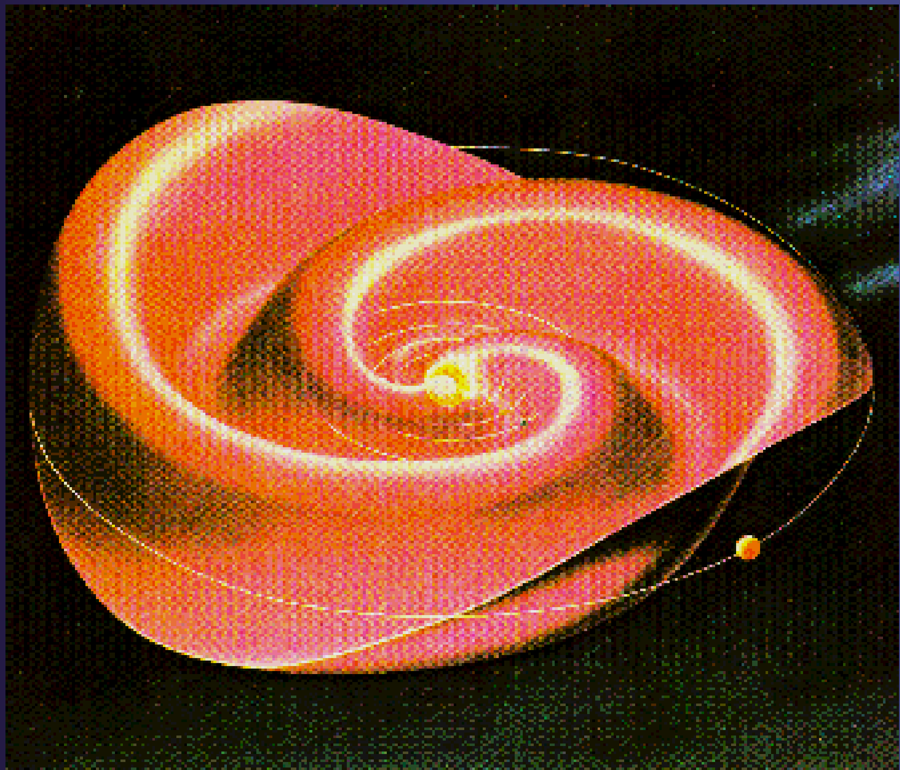
$$\psi(r,\theta,\phi) = R\sum_{n=1}^{\infty}\sum_{m=0}^{n}\left[\left(\frac{R}{r}\right)^{n+1}(g_n^m\cos m\phi + h_n^m\sin m\phi)P_n^m(\theta)\right]$$

$$B_l = B_r\sin\theta\cos(\phi-\phi_0) + B_\theta\cos\theta\cos(\phi-\phi_0) - B_\phi\sin(\phi-\phi_0)$$

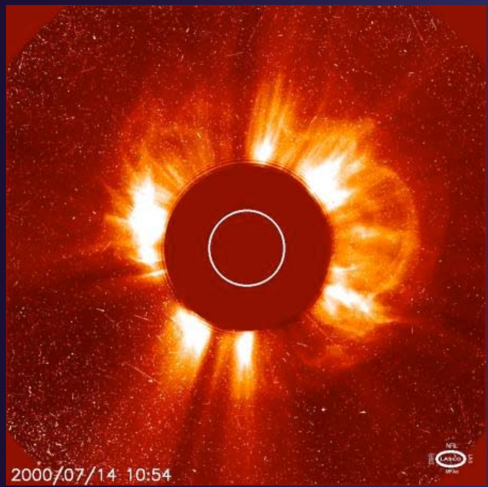
# Computed Br at R=2.5Rs



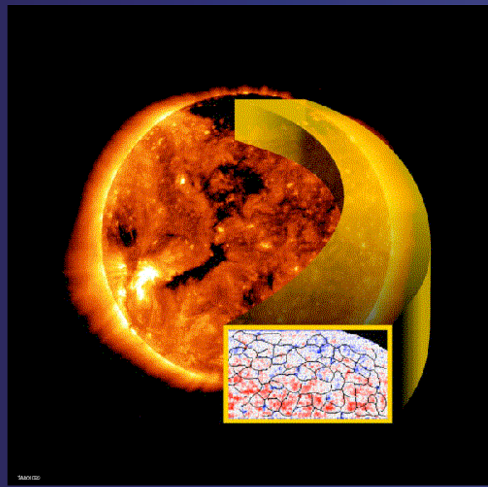
# The heliospheric current sheet



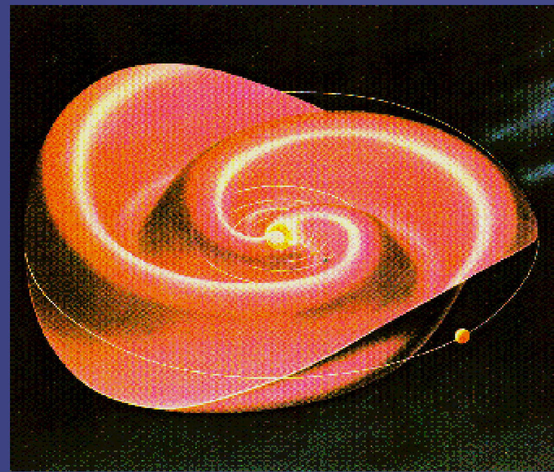
# The solar wind




Fast halo CME



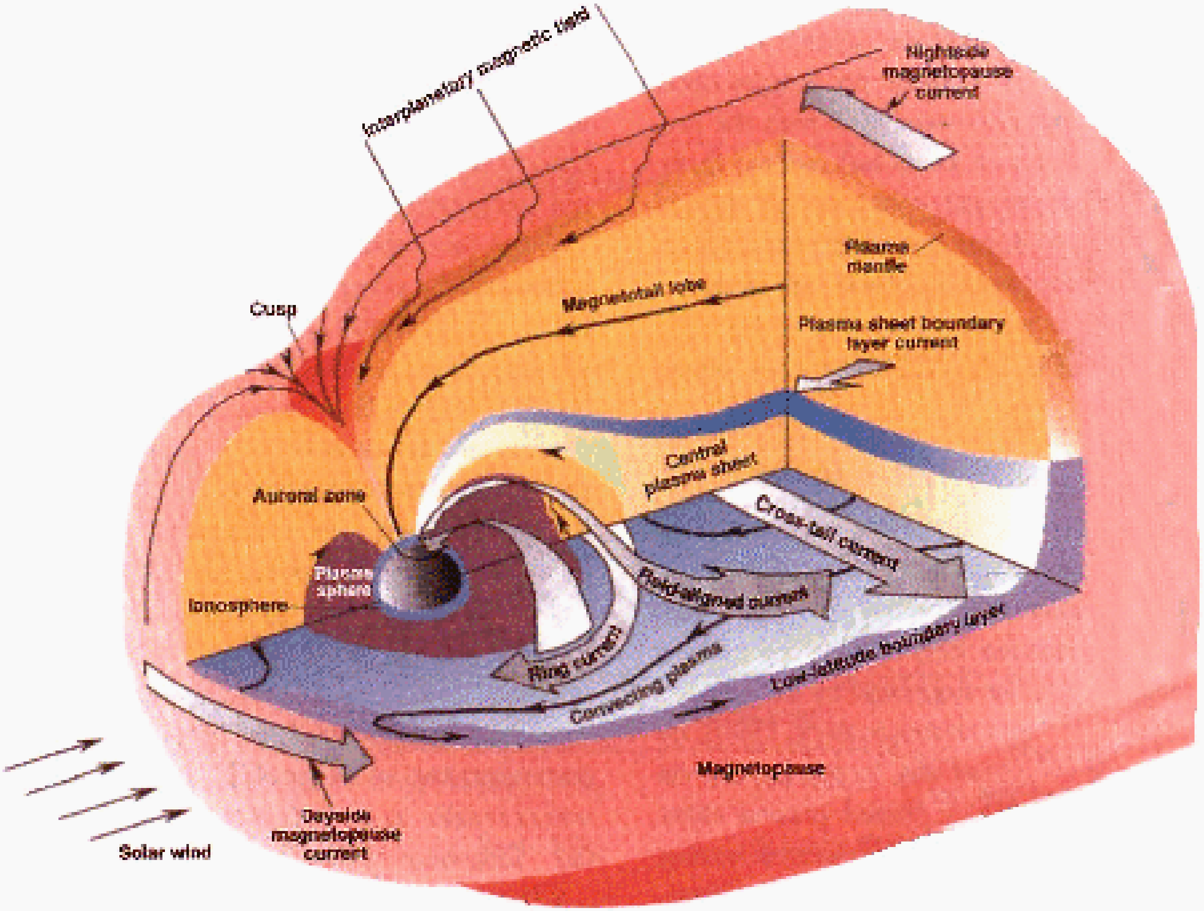
Fast continuous solar wind from coronal holes



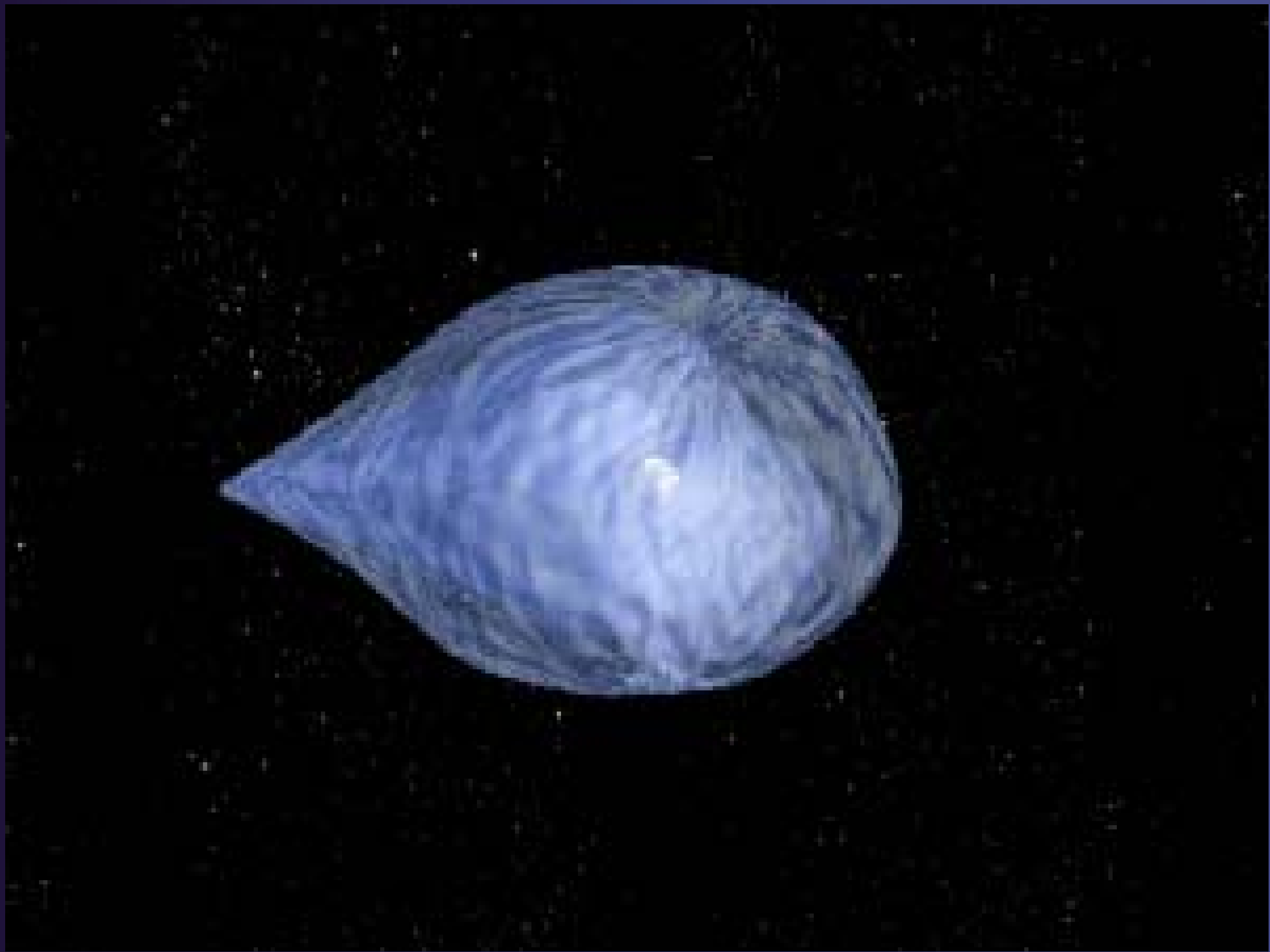
Heliospheric current sheet

The solar wind Bz, V, and n determine the effect of the solar plasma.

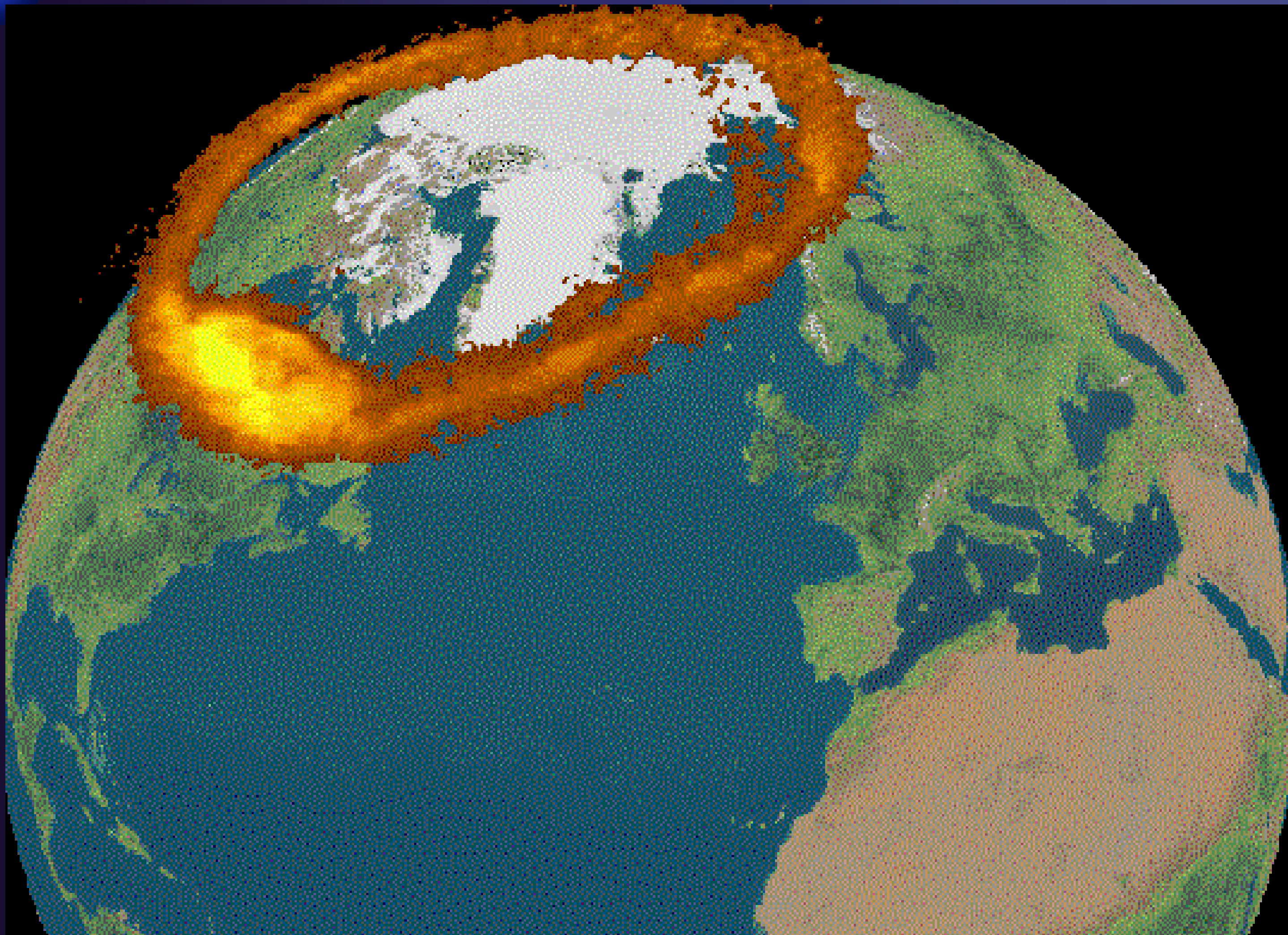
# Solar wind-magnetosphere coupling: Earth's magnetosphere and current systems



# Solar wind-magnetosphere coupling



# Aurora oval



# Aurora during severe solar storms

Aurora was observed in Italy 6-7 April and on July 15-16, 2000!

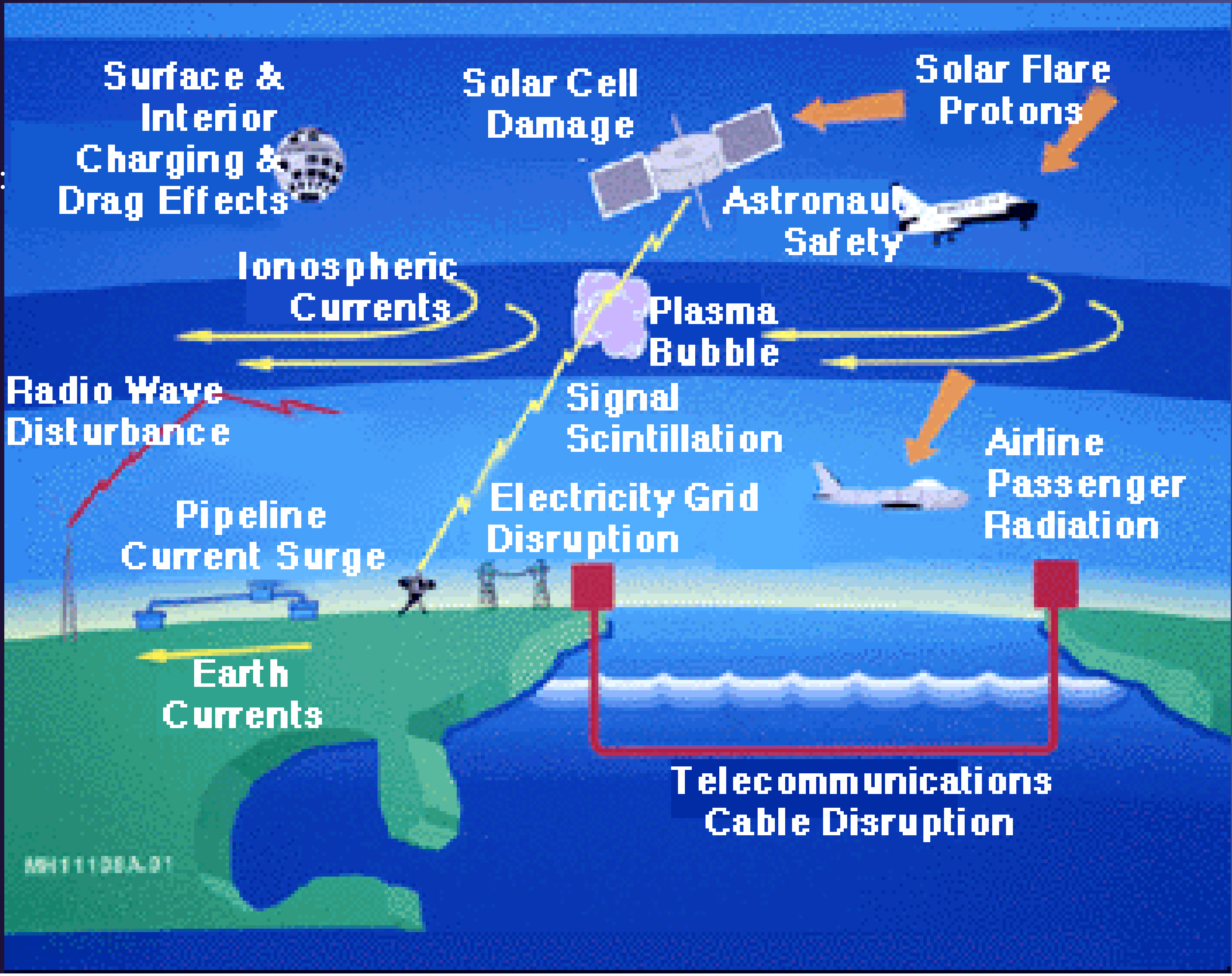

The aurora observed in Stockholm

# Space weather effects on technological systems

Satellite anomalies:
Caused by CME protons, HSPS e- X-ray flare heating

Communication/ Aviation problems:
Caused X-ray flares

Groundeffects:
Caused by CME-, HSPS- and shock caused geomag.storms



# Satellite anomalies

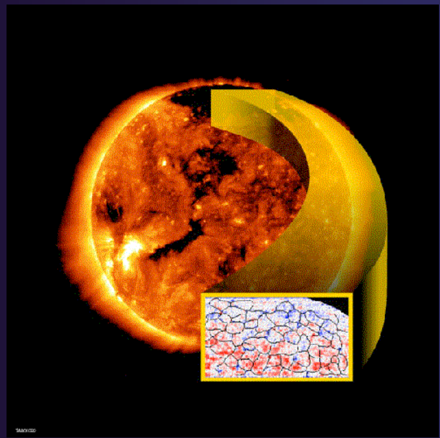


Figure courtesy of The Solar Data Analysis Center

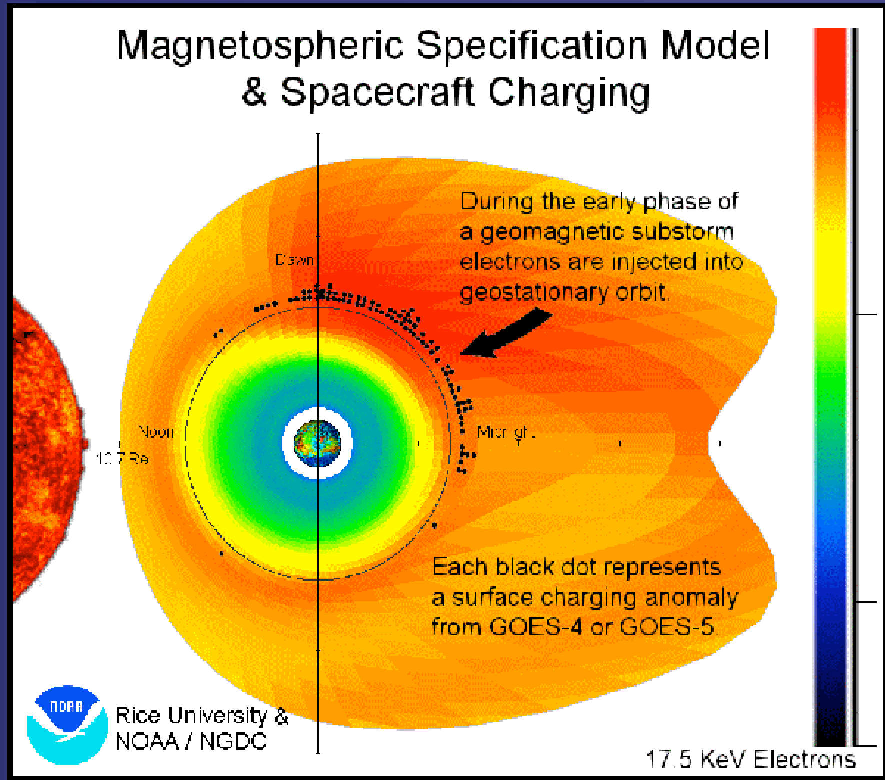
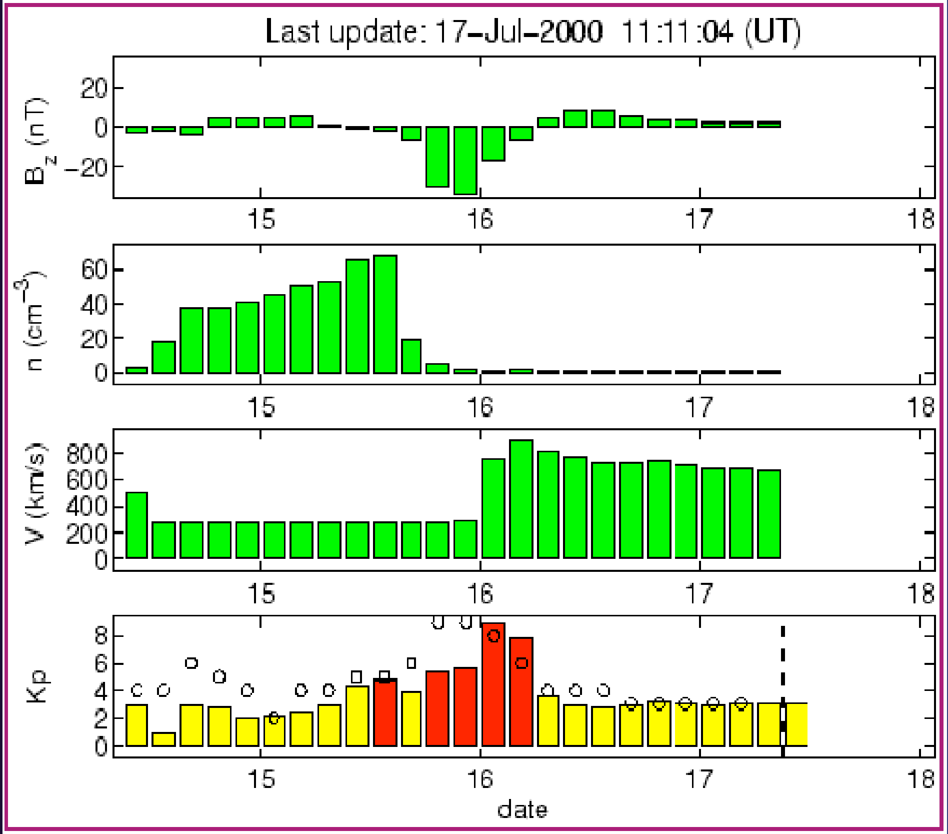


Figure courtesy of The National Geophysical Data Center

# Satellite anomalies of July 14-16, 2000 event




The proton event caused problems for ACE, SOHO, Ørsted, Japanese X-ray satellite, star trackers on board commercial satellites.

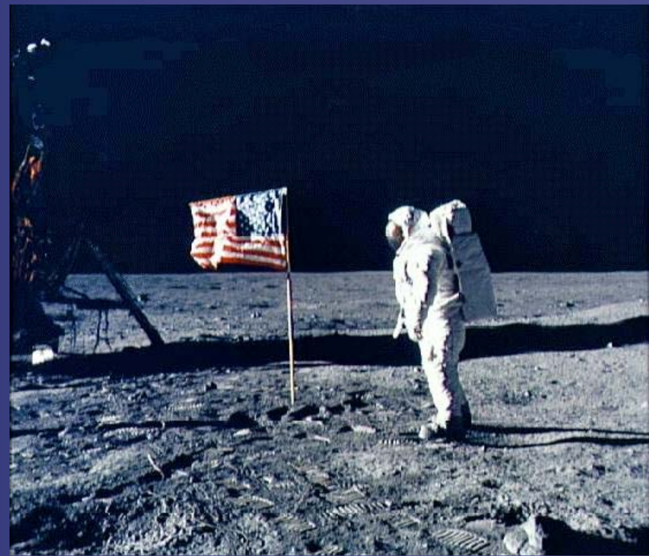
Proton flux (pfu) > 10 MeV, 24000 pfu (July 15, 12.30 UT). Third largest!

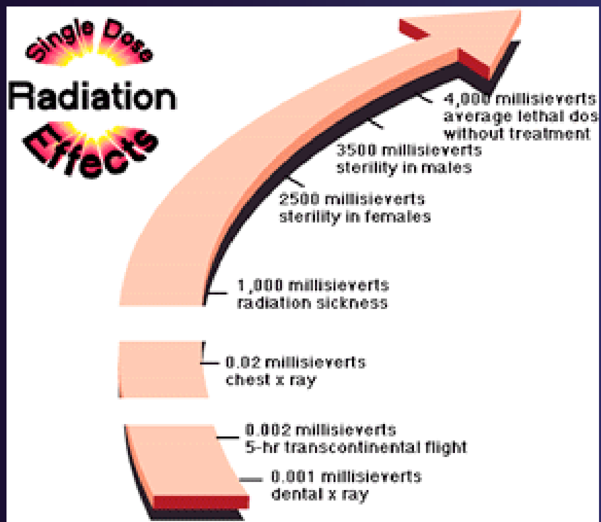
Largest 43 000 pfu, (March 24, 1991). Second 40 000 pfu (October 20, 1989).

Today IRF-Lund has real-time neural networks forecasts of satellite anomalies one day in advance (ESA project SAAPS). The work has been in collaboration with Swedish satellite operators (ESRANGE).

# Solar proton events are dangerous to man in space


Mars






Between Apollo 16 and 17 a proton event occurred, which should have been deadly to the astronautes within 10 hours (i.e. above 4000 mSv).

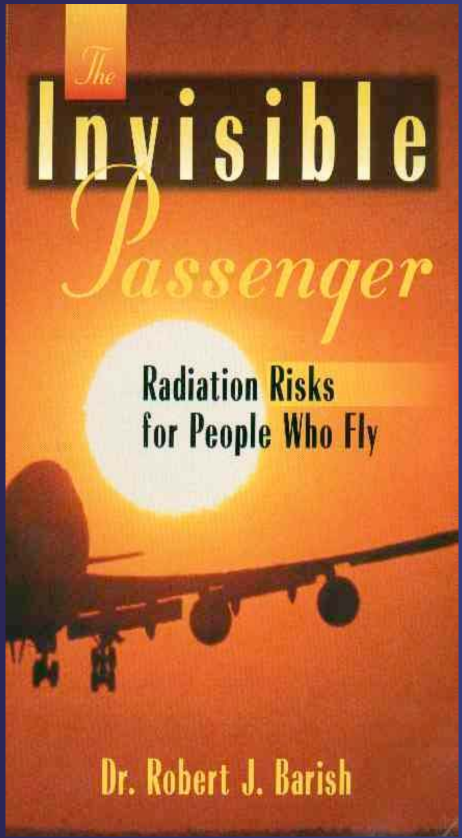
# Radiation risks and aviation

The radiation exposure is doubled every 2.2 km.

Solar flares can increase the radiation by 20-30 times.

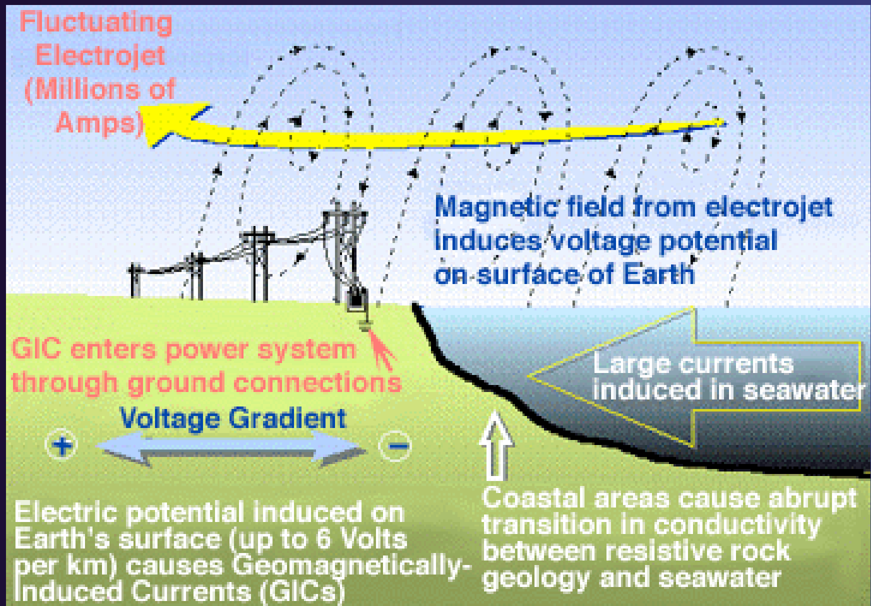
Pilots get cancer more often than average.

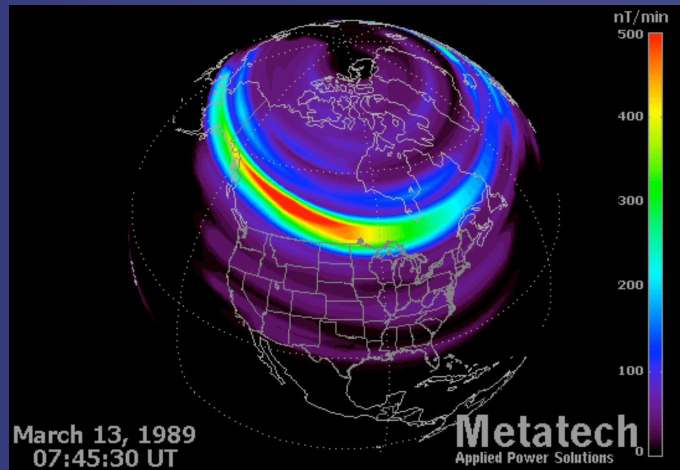
New EU law:
Pregnant (aircrew) should
not be exposed to more than 1 (1-6) millisievert/year




The intensive solar flare of April 2, 2001, which caused major communication problems also made Continental Airlines to change their route between Hong Kong and New York.

# Electrical systems: Telegraph, gas pipeline and power systems

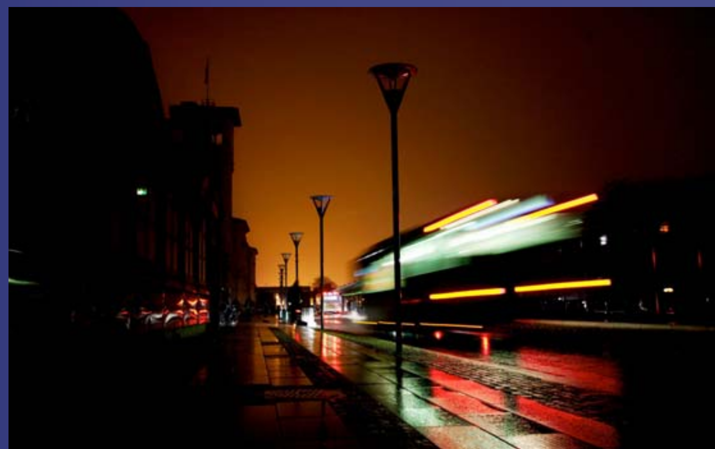




Forskarrapport om korrosion visar

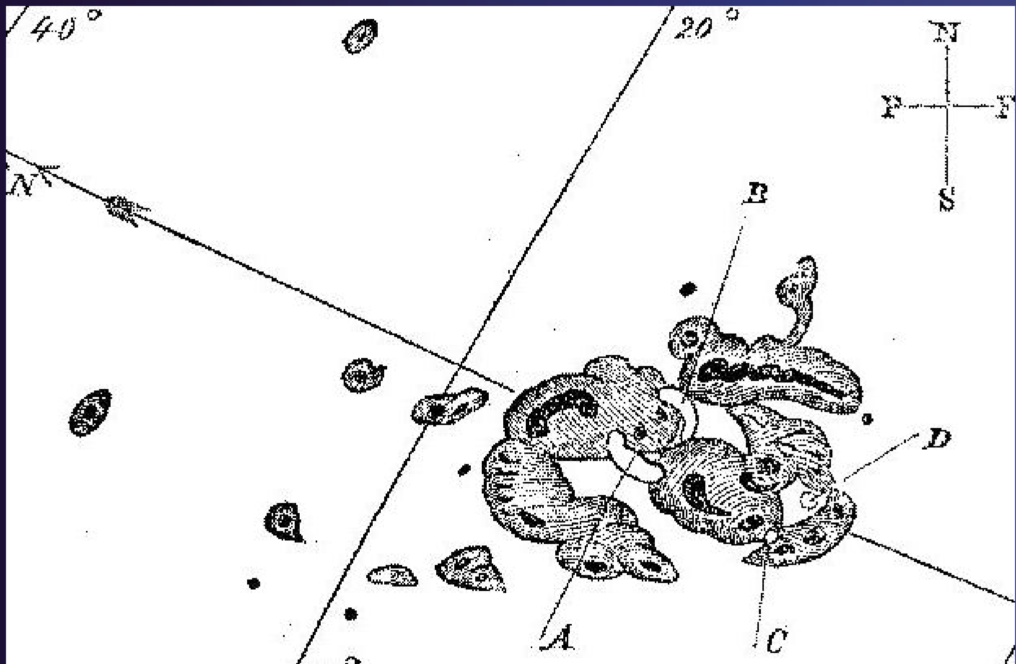
Solstormar fräter på rören



# Precursors of solar drivers

- Appearance of large spots/AR on solar center
- Dissapearig filaments/CMEs
- AR's magnetic complexity
- Activity below solar surface and farside activity

# Carrington event 1859, September 1
# Dst = -1750nT

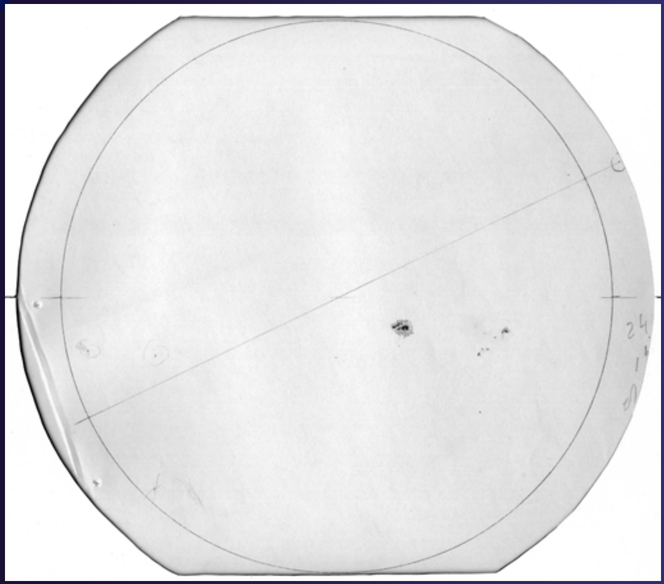



September 1-2, 1859:
Dst = -1760nT
(Superstorm <-300nT !!)

A magnetic storm from August 28 to September 2 produced widespread effects on the telegraph system in Europe and North America.

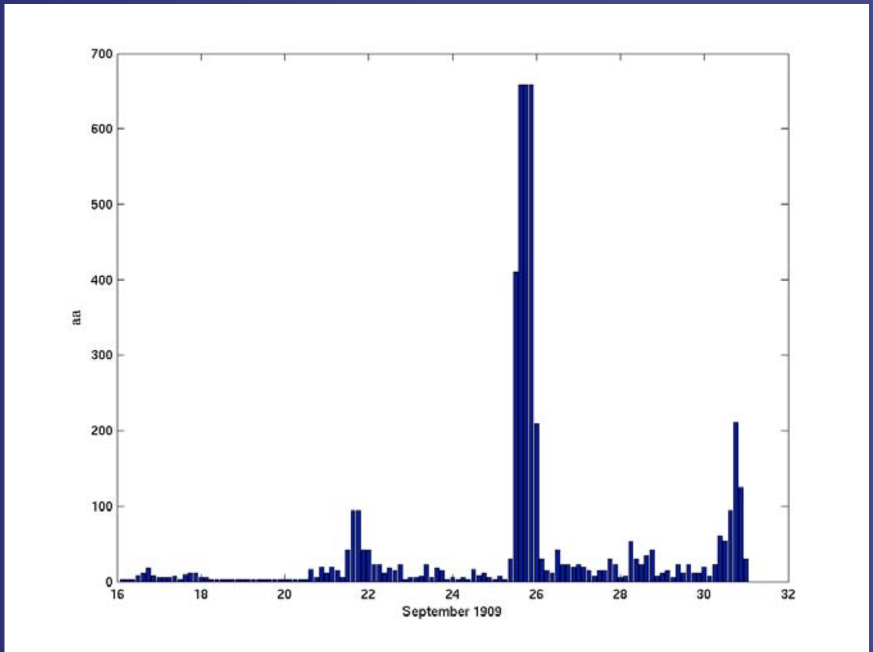
Next Gleissberg maximum 2030-2040! - Long-term warning.

# The Sun September 24, 1909



A flare was observed (spectroheliogram) by James Lockyer 10-11 a.m. (UT) September 24 . The associated CME caused a geomagnetic storm on September 25.

The observation was made at Kalocsa,Hungary




September 25,1909
aa = 658, 12-18

(March 1989 aa = 715, 13/3 21 - 3 14/3)

# The magnetic storm 1909
# September 25

THE MAGNETIC STORM

OF SEPT. 25 1909

BY

DAVID STENQUIST

INAUGURAL DISSERTATION

THE UNIVERSITY OF STOCKHOLM DEC. 1914.

CHAPTER II.

EARTH-CURRENTS.

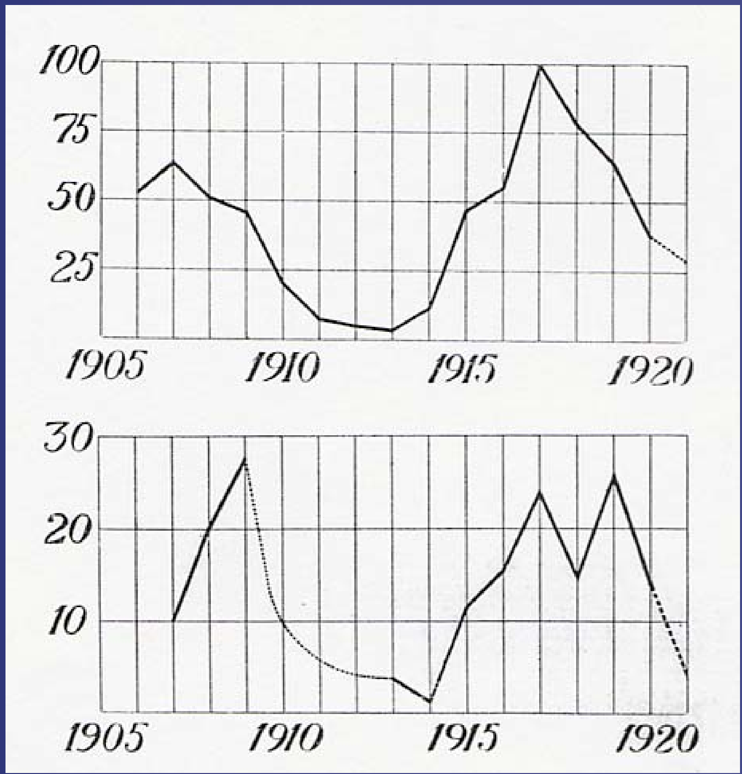
Strong earth-currents disturbed the telegraphic communications over the whole globe on Sept. 25 th. At Stockholms Telegraph office the currents began between $9^h$ and $10^h$ a.m.[1]) on the morning of the 25th inst. The did not exceed 10 milliamperes however before $12^h$ $50^m$ a.m. when the currents increased within a couple of minutes to a force exceeding 250 milliamperes on several wires, for instance Stockholm-Christiania. To proove this fact, we know that safety pieces made of Wood's metal melt at this force of current. Between $12^h$ $50^m$ p.m. and $5^h$ p.m. the force of current seldom fell under 250 milliamperes. On the wire named the resistance is 5,4 ohms per km and therefore the tension exeeded 1,35 volts pr km. Earth-currents were first observed at the Telephone office on the wires to Luleå. The operator on duty at these wires received a sudden shock, half her hand turning white and two of her fingers being paralyzed. Two or three minutes after $12^h$ $50^m$ p.m. particularly strong disturbances were also observed on most of the wires going southwards. The strong increase probably took place at exactly the same time in all directions. When taking hold of a microphone, both the instrument and the hand were surrounded with an intense, diffuse light, casting out sparks and causing blisters. A measurement on a double wired copper line of $4\,^1/_2$ mm between Stockholm and Luleå

[1]) In the following all times given are mid-European, excepting in table XXIII.

# The first GIC network!

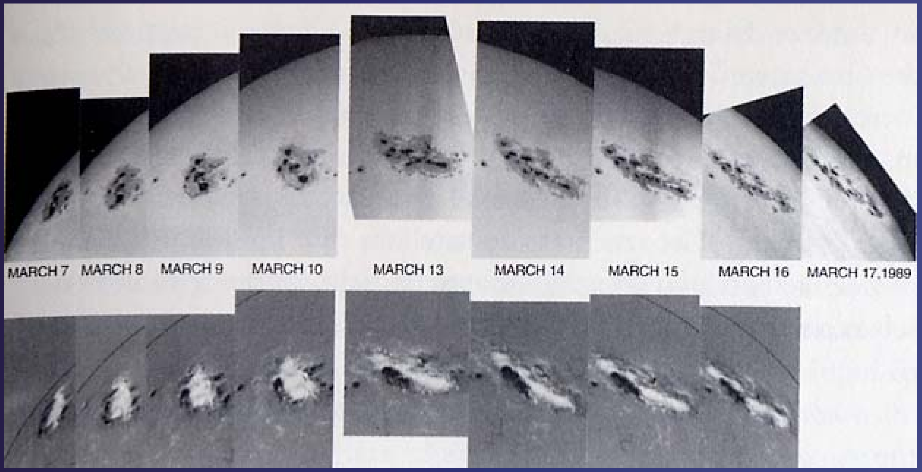
GICs were regularly measured at four places (1910-1925 at least)

- Observatorio de fisica cosmica del Ebro in Spain
- Huancayos Observatory in Peru
- Watheroos magnetic observatory , west Australia
- Älfsjö just outside Stockholm, Sweden




Sunspots and the number of days during every year, telegraph operation was disturbed at Stockholm’s Central Telegraph station.

# The March 1989 event



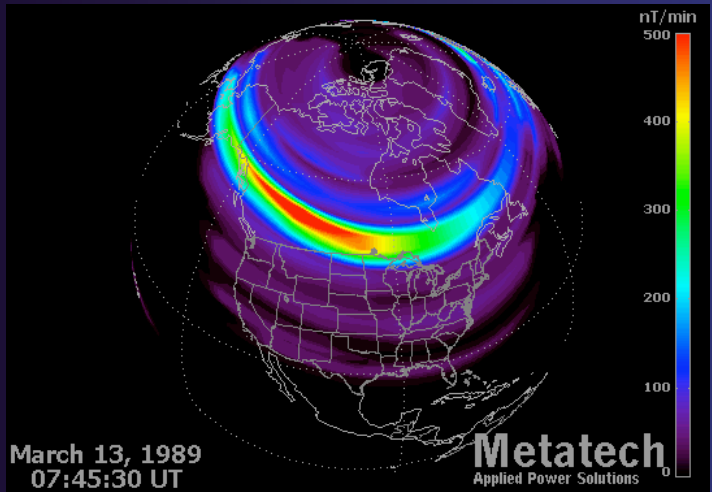

A white-light flare was observed on March 10 at AR 5935 and the SMM satellite's coronograph detected a large halo CME.
Late on March 13 the CME reached Earth.
The geomagnetic storm index Dst reached -589nT.

**Superstorms: Dst < -300nT : 21 since 1957**

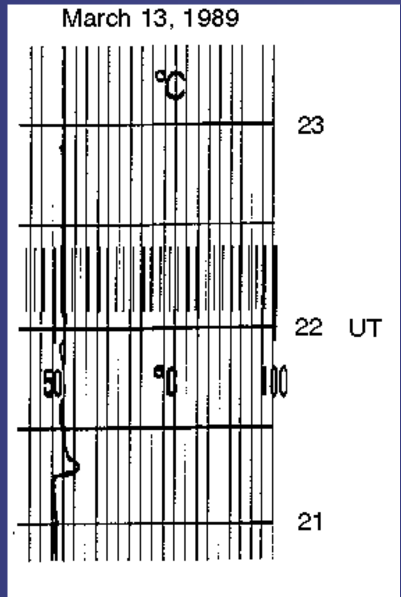
- October 29, 2003: Dst = -308nT
- October 30, 2003: Dst = - 342nT
- November 20, 2003: Dst = - 429nT

- March 14, 1989: Dst = -589nT

# The severe event 13/14 March 1989

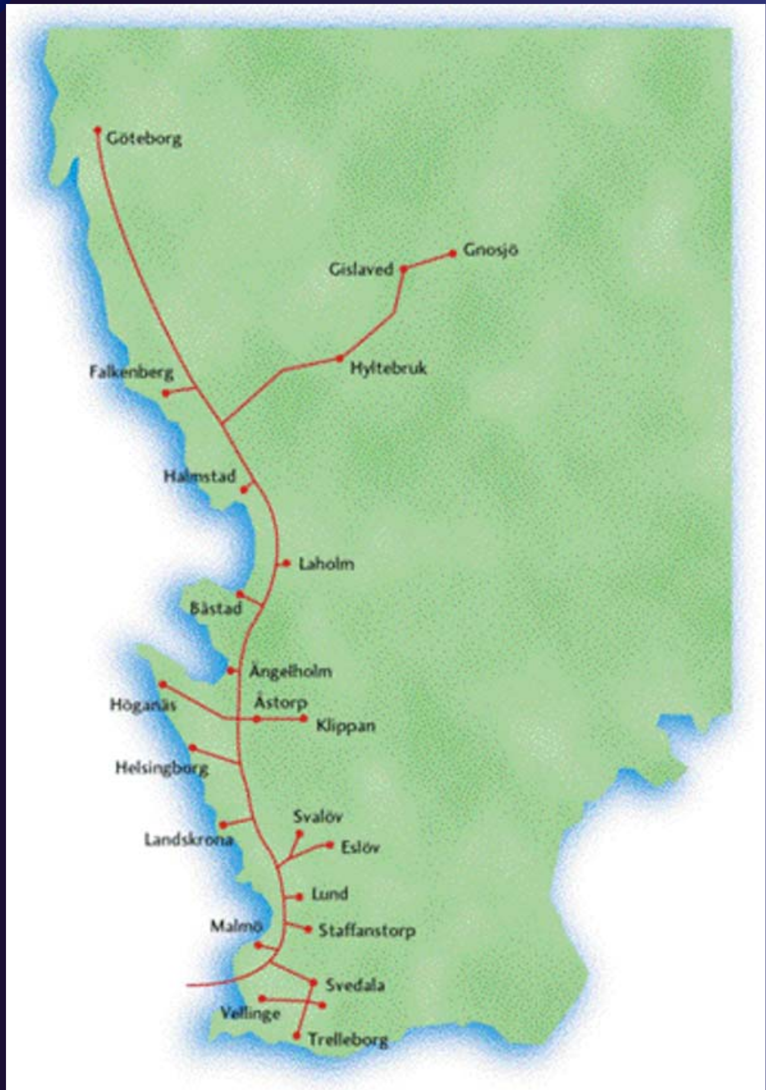



This severe electrojet caused the failure of Quebec's power system March 13-14, 1989.




One of the generators of OKG's (Sydkraft's) nuclear plants was heated due to the geomagnetically induced current in March 13-14 1989.

# Corrosion of pipelines due to GICs




*Forskarrapport om korrosion visar*

## Solstormar fräter på rören

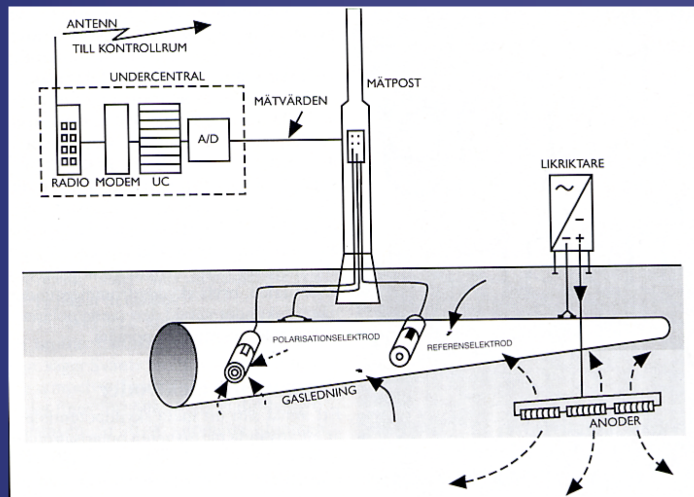
**Eruptioner på solen kan påverka rostskyddet på naturgasledningarna. Det är ett relativt nytt problem i Sverige som svenska rostskydds- eller korrosionstekniker nu måste ta hänsyn till, visar en undersökning gjord av Korrosionsinstitutet.**

**Magnetiska stormar ger ström**

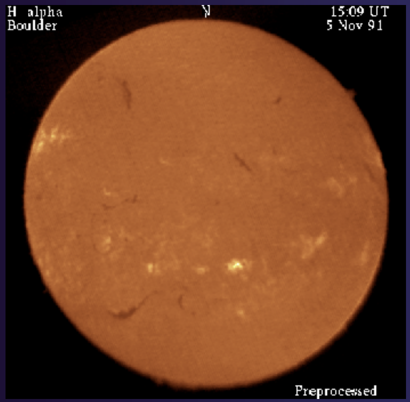
**Rostskyddet slås ut**

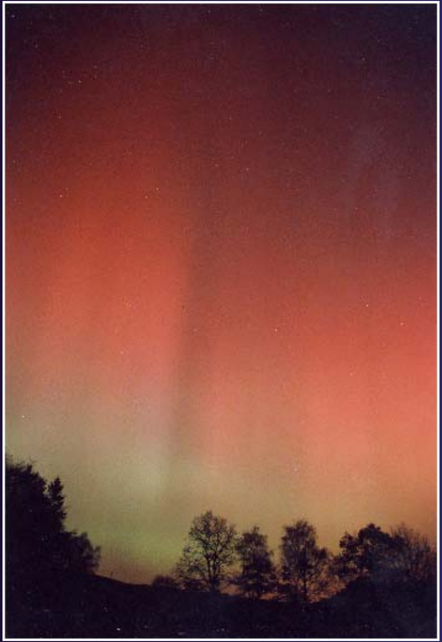
**Jordade ledningar motåtgärd**

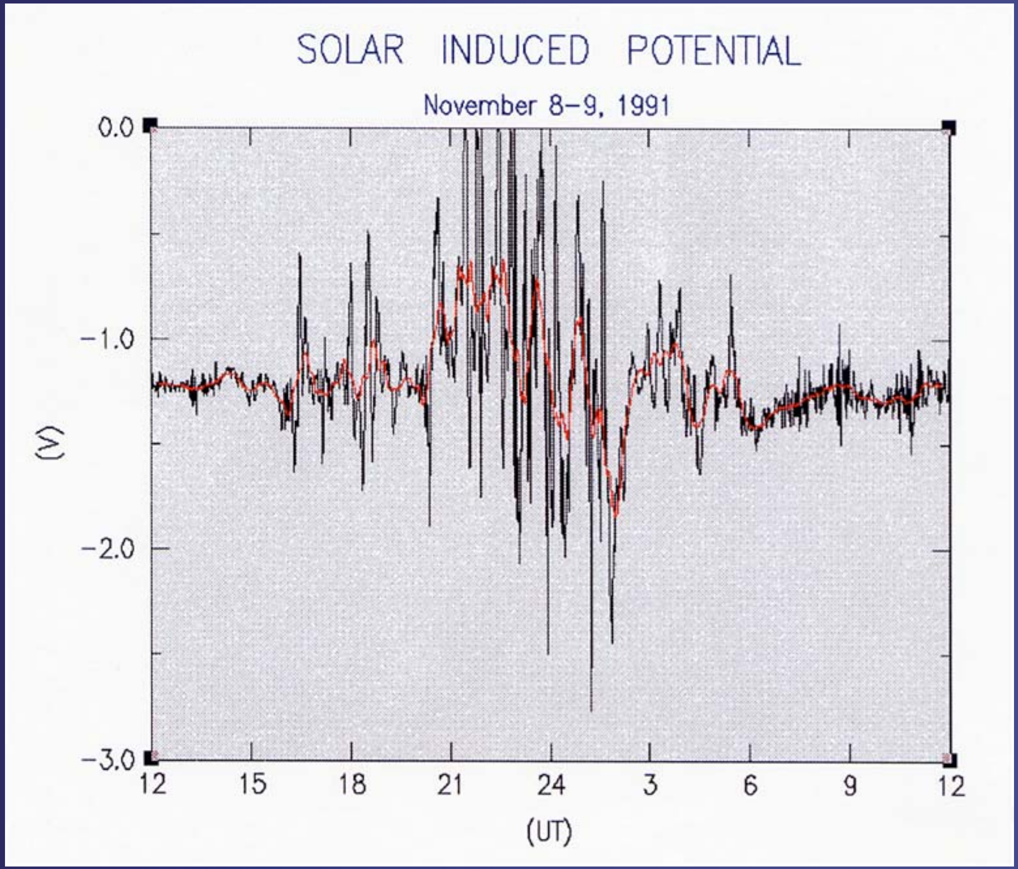
ANNIKA ÅGREN



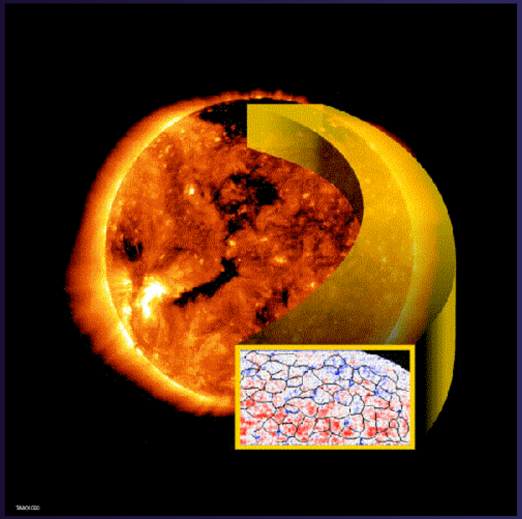
# GIC effects in Swedish pipeline systems November 8-9, 1991

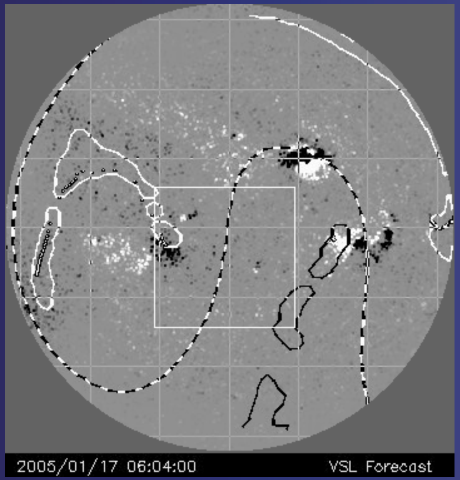


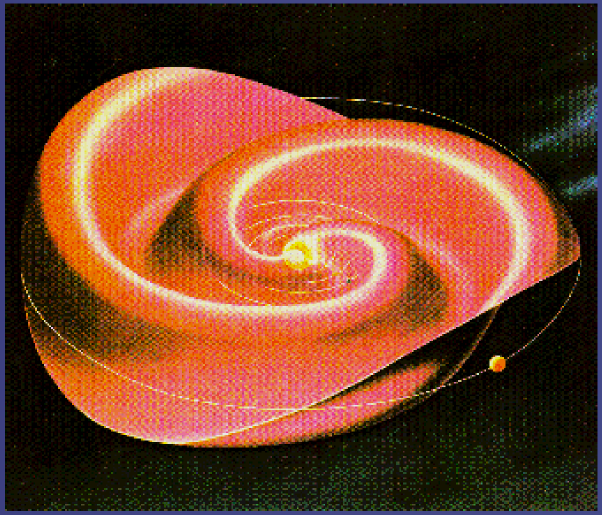





# $27^d$ solar variability due to solar rotation



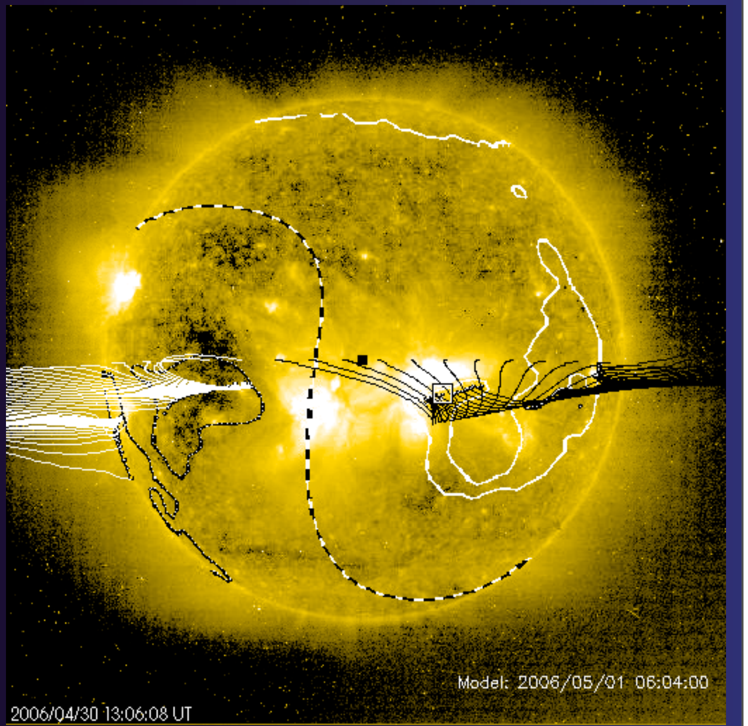


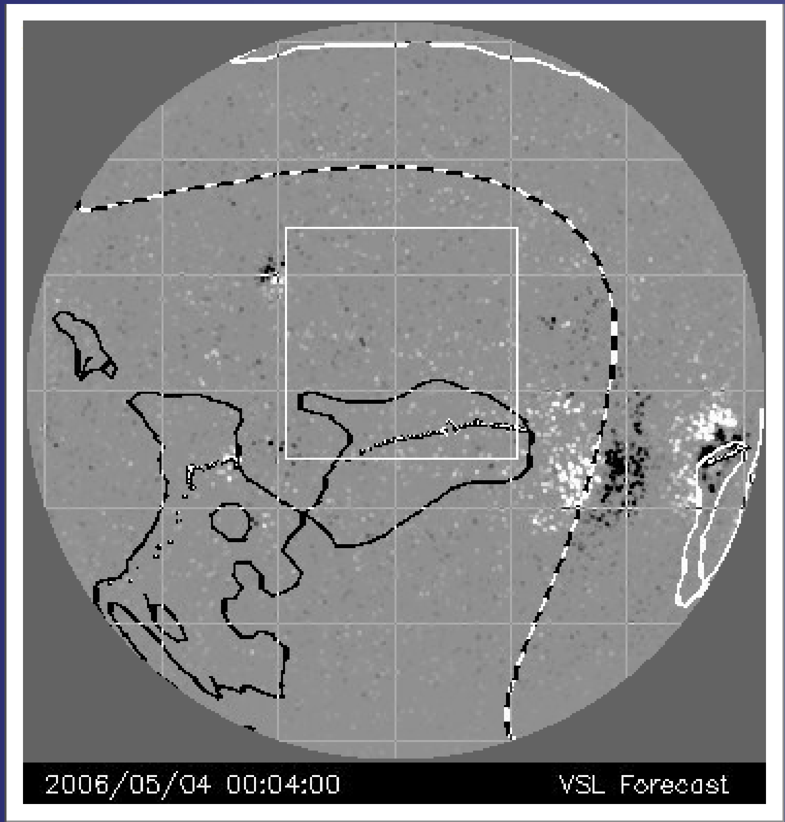



Fast solar wind from coronal holes

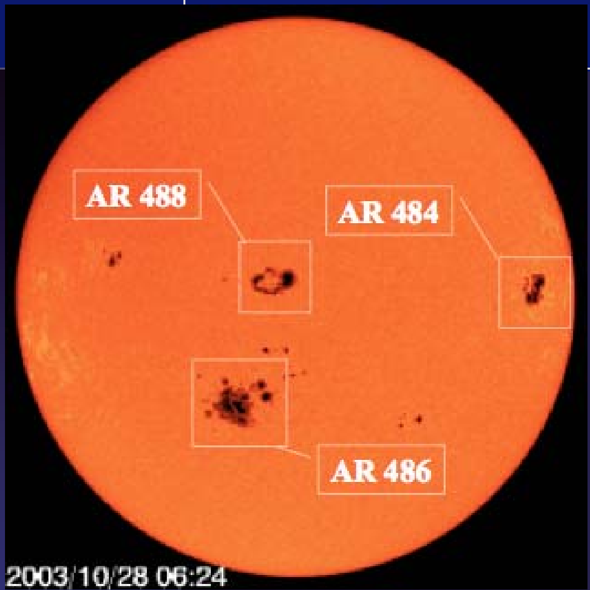
Heliospheric current sheet

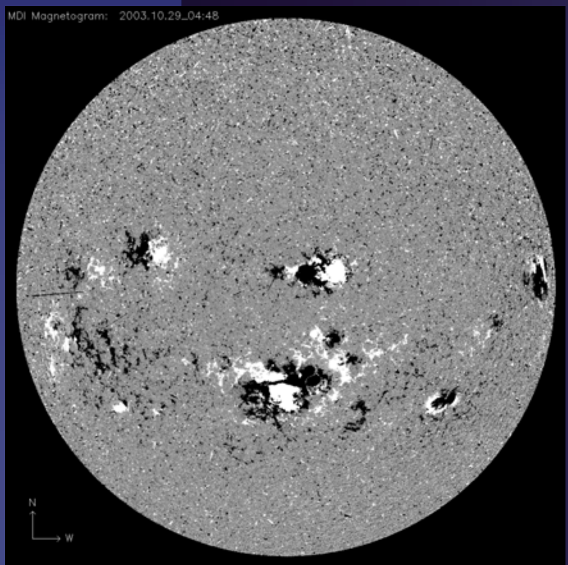
# PF model calculation gives coronal holes and HCS



# Mount Wilson Classification




**Mount Wilson magnetic classification.** Classification of the magnetic character of sunspots according to rules set forth by the Mount Wilson Observatory in California.

alpha (α). A unipolar **sunspot** group.

beta (β). A sunspot group having both positive and negative magnetic polarities (bipolar), with a simple and distinct division between the polarities.

gamma (γ). A complex **active region** in which the positive and negative polarities are so irregularly distributed as to prevent classification as a bipolar group.

beta-gamma (β-γ). A sunspot group that is bipolar but which is sufficiently complex that no single, continuous line can be drawn between spots of opposite polarities.

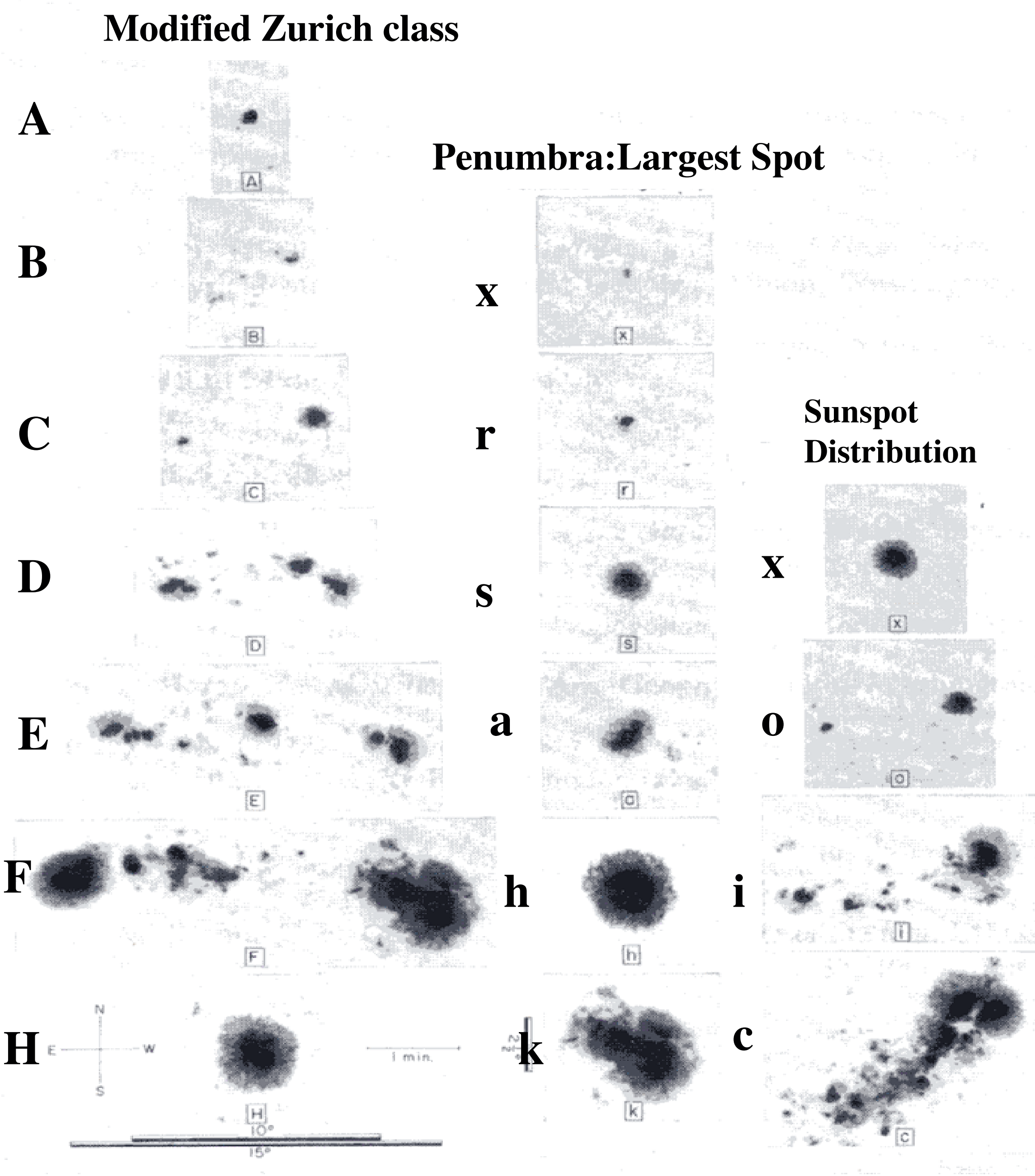
delta (δ). A qualifier to magnetic class (see below) indicating that **umbrae** separated by less than 2° within one **penumbra** have opposite polarity.

beta-delta (β-δ). A sunspot group of general *beta* magnetic classification but containing one (or more) *delta* spot(s).

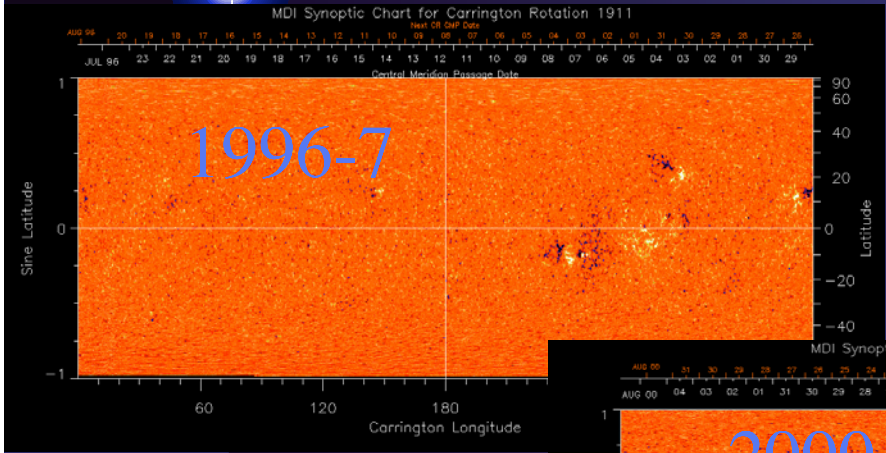
beta-gamma-delta (β-γ-δ). A sunspot group of *beta-gamma* magnetic classification but containing one (or more) *delta* spot(s).

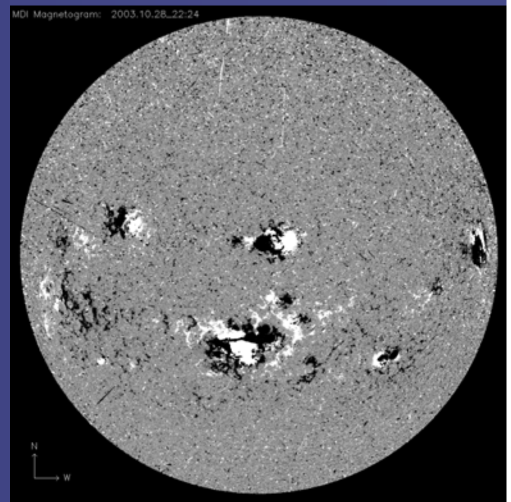
gamma-delta (γ-δ). A sunspot group of *gamma* magnetic classification but containing one (or more) *delta* spot(s).

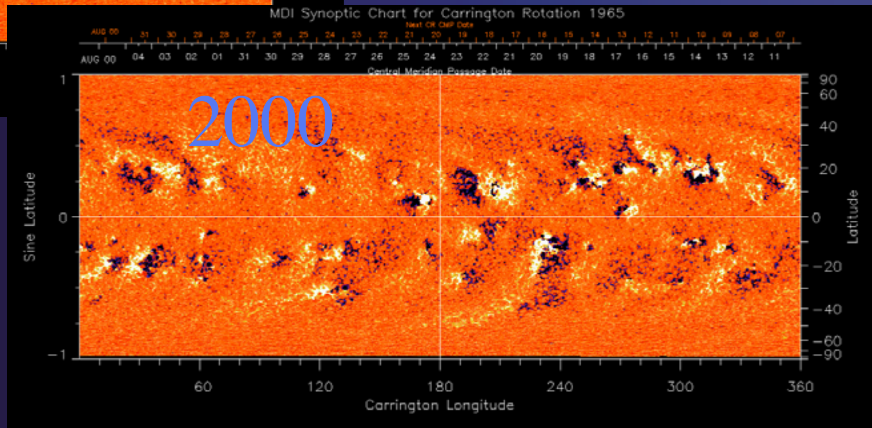
# APPENDIX C: MODIFIED ZURICH (McINTOSH) SUNSPOT CLASSIFICATION

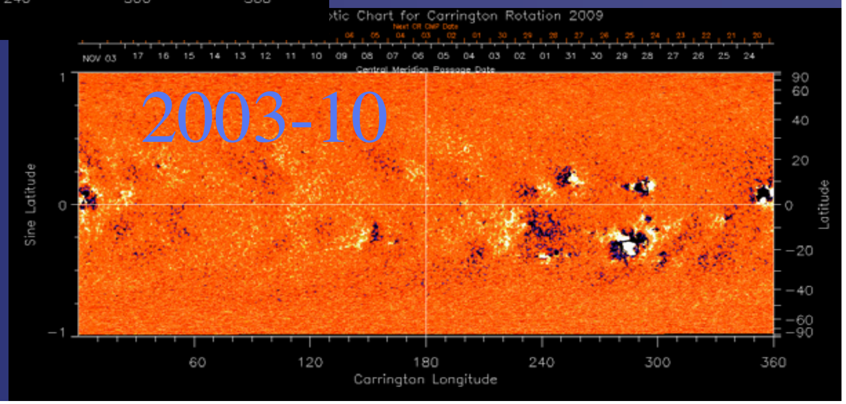


# Magnetic field complexity



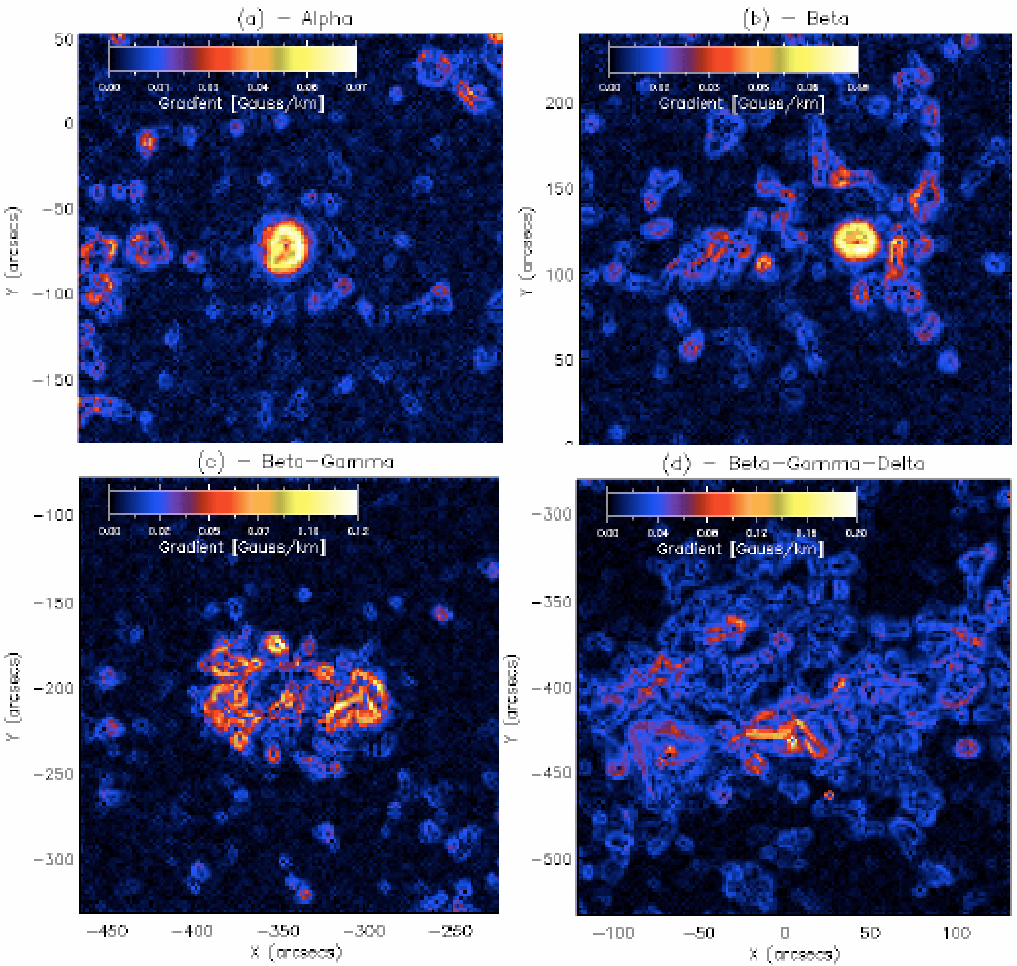
# Precursors

## *Active Region Characterisation*

Include measures that are physically motivated and that give a measure of energy storage/release:

- **Fractal dimension:** relates to the active region complexity.
- **Field gradient:** indicative of energy build-up in the photosphere.
- **Neutral lines:** related to energy release locations.
- **Emerging flux regions:** can act as energy release triggers.
- **Wavelet analysis:** diagnostic of small and large scale morphology.

# Large gradients




## *Horizontal Gradient - Example*

- Gradients are large for ***large fields in close proximity.***

# Fractal dimension

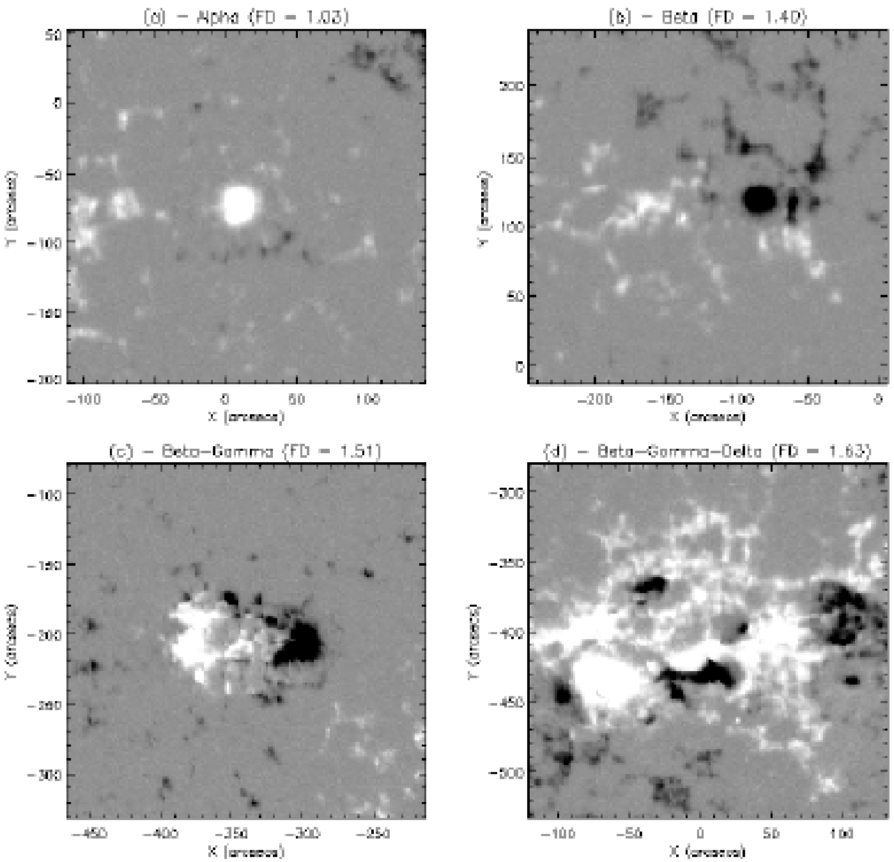
### *Fractal Dimension - Methods*

- **Box-Counting Dimension** (Mandelbrot):

$$N(\varepsilon) = \varepsilon^{-\delta_{BC}}$$

- The box-counting dimension can then be then determined from the slope,

$$\delta_{BC} = \frac{\log(N(\varepsilon))}{\log(1/\varepsilon)}$$



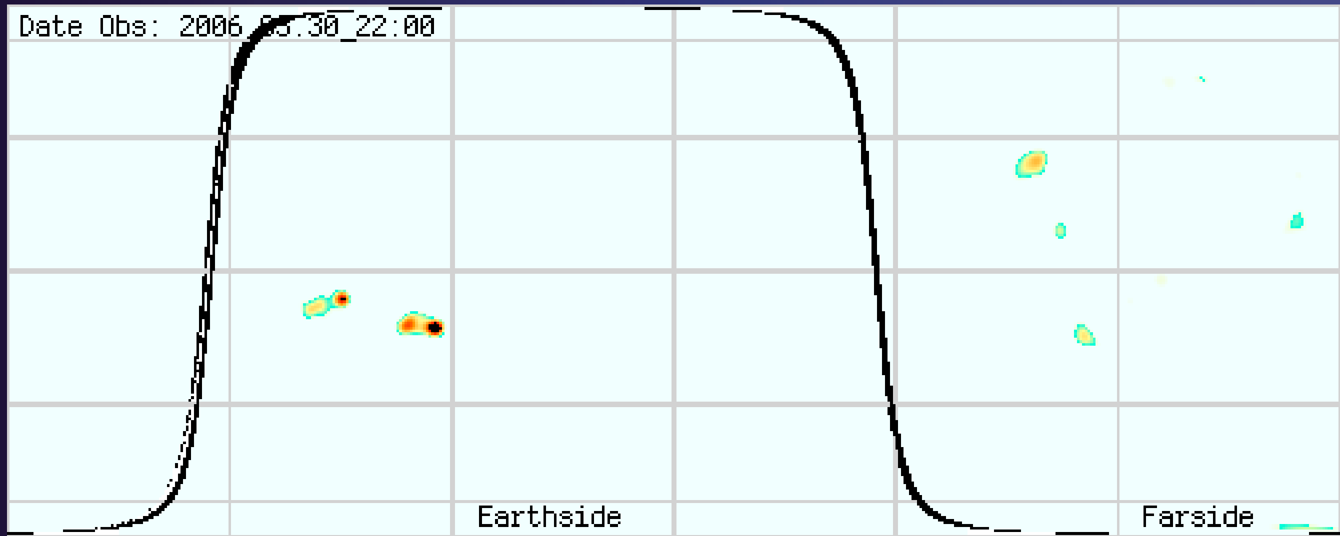

## *Fractal Dimension - Example*

- $\alpha \sim 1.0 - 1.2$
- $\beta \sim 1.2 - 1.4$
- $\beta\,\gamma \sim 1.4 - 1.6$
- $\beta\,\gamma\,\delta \sim 1.5 - 1.7$

- Error ~ ± 0.1

*www.SolarMonitor.org* *Peter Gallagher (UCD)*

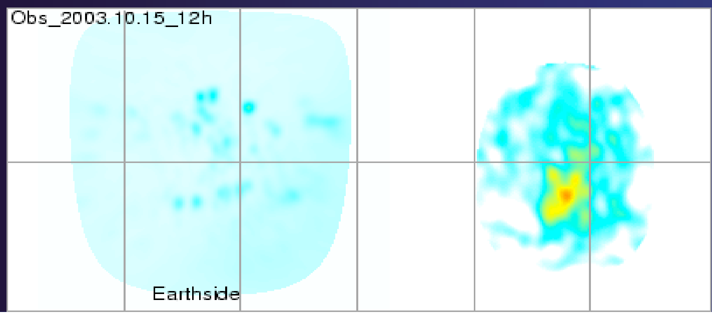
# Magnetic maps of the WHOLE Sun
# SOHO/MDI/Stanford/P. Scherrer

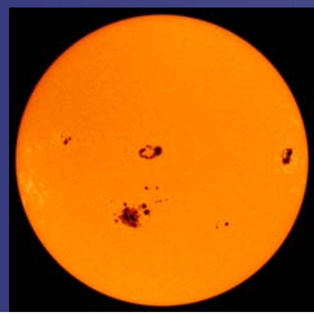



**Farside images computed from MDI sound travel time analysis.**
**Earth-side images are magnetic flux observed by SOHO-MDI.**
**These files are updated daily!!**

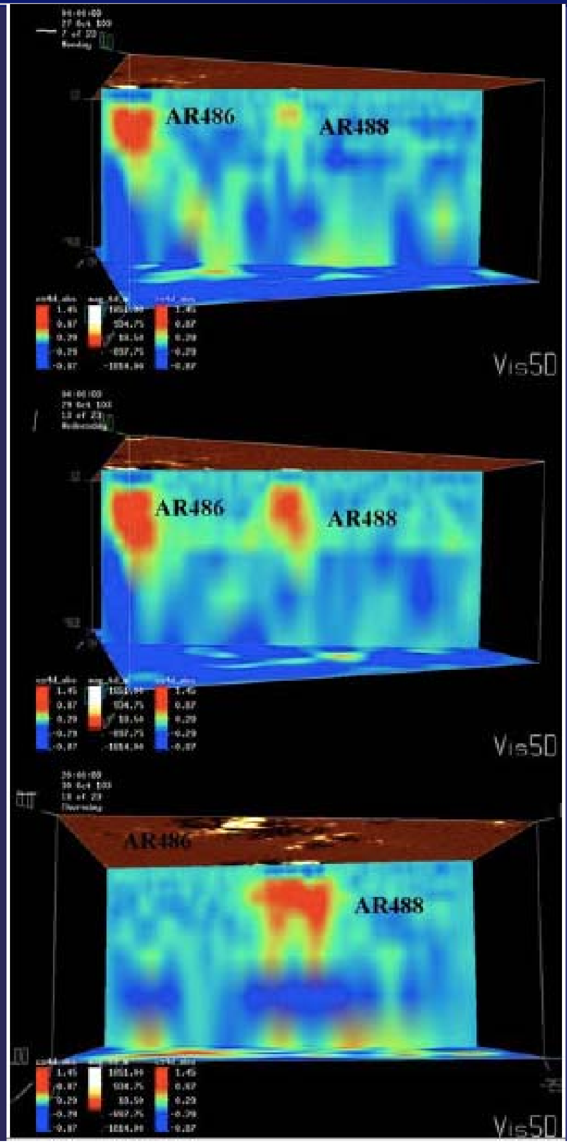
14-15 Oct, 2003

30 Oct, 2003

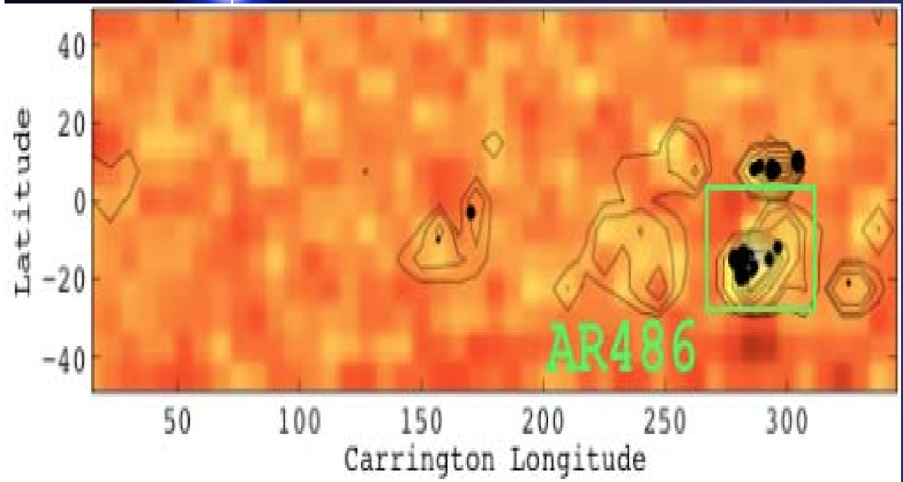



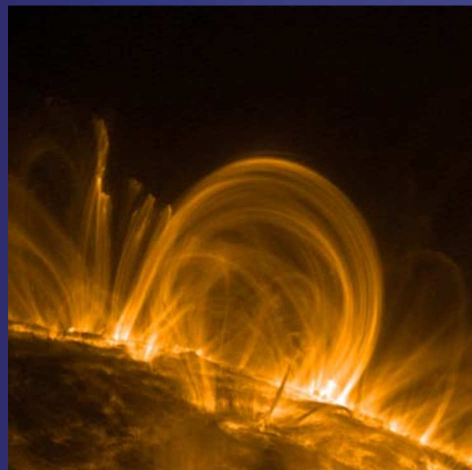
# Activity below solar surface precursor of surface activity



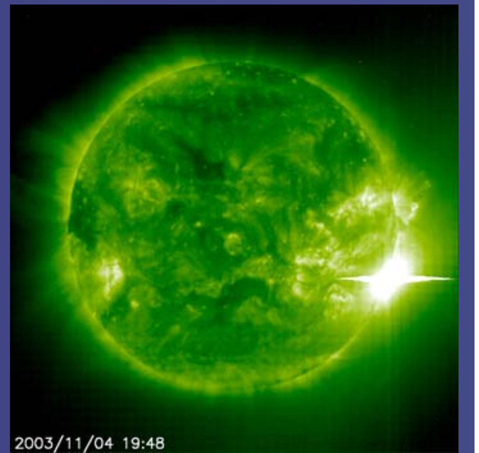

Kosovichev, A.G, IAU Symp., 223, 2004

# High resolution solar magnetic field and helioseismic observations give a new picture: of correlated activity below, on surface in corona

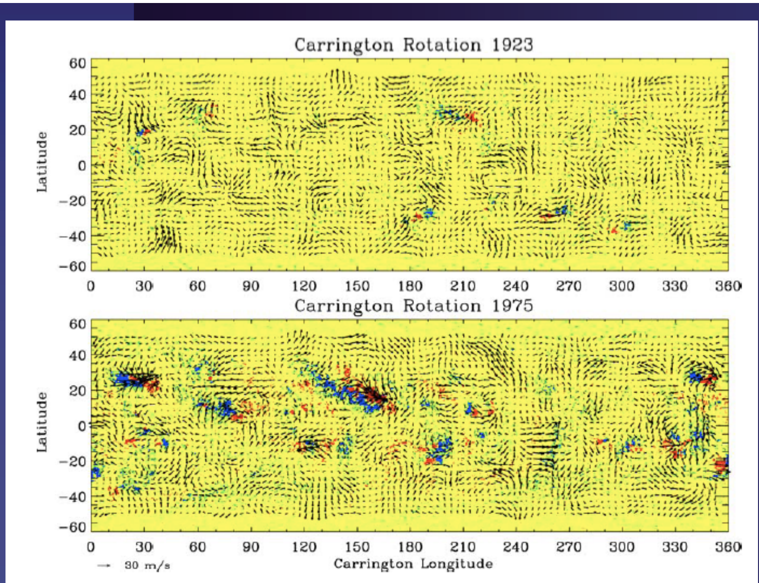


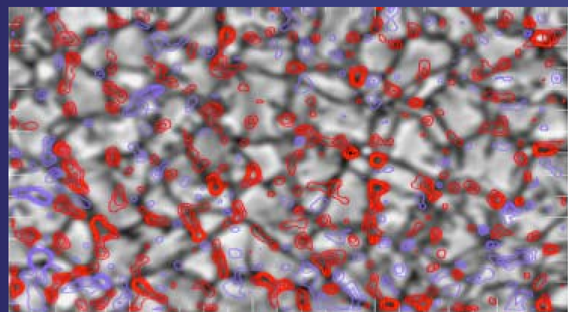
TRACE



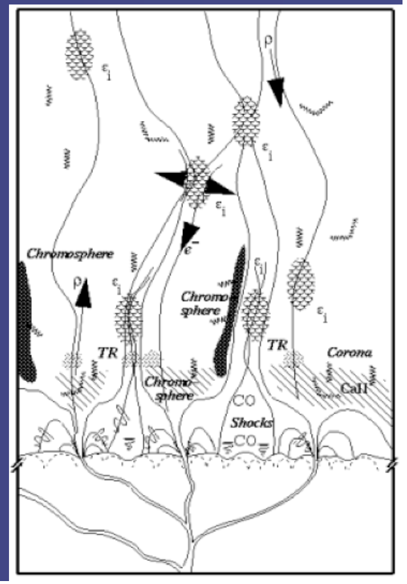

SOHO/EIT




SOHO/MDI



La Palma



# THE END

of

Third Talk