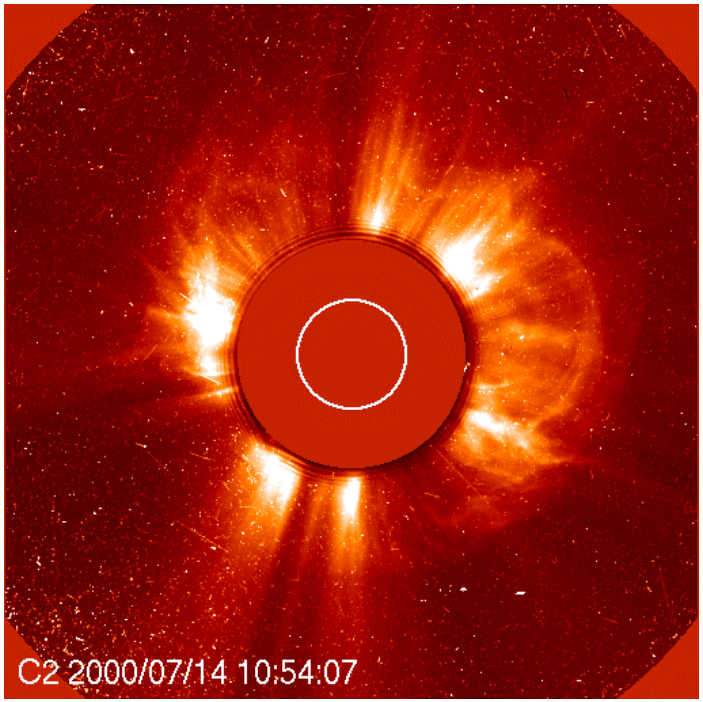
The in situ characteristics of storms in the rising phase of solar cycle 23 - How to forecast geomagnetic storms reliably ?



Volker Bothmer

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D-37191 Katlenburg-Lindau, Germany

& Cargill P.(2), Dmitriev A.(3,4), Romashets E.(5), Veselovsky I.(3), Zhukov A. (3,6)

INTAS-EU 99-00727 Team

2) Imperial College of Science Technology and Medicine, The Blackett Laboratory, Exhibition Road, SW7 2BZ London, United Kingdom; 3) Institute of Nuclear Physics, Moscow State University, 119992, Moscow, Russia; 4) Institute of Space Science, National Central University, Chung-Li, 320, Taiwan; 5) Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, 142190, Troitsk, Russia; 6) Royal Observatory of Belgium, Avenue Circulaire 3, B-1180, Brussels, Belgium

Introduction

- In a joint EU/ESA-INTAS project we are analyzing the interplanetary causes and solar sources of geomagnetic disturbances with Ap>20 (Kp > 3+) for the years 1997-2001, i.e. during the rise and maximum of solar cycle 23. Additionally also the D_{st} index was taken into account.

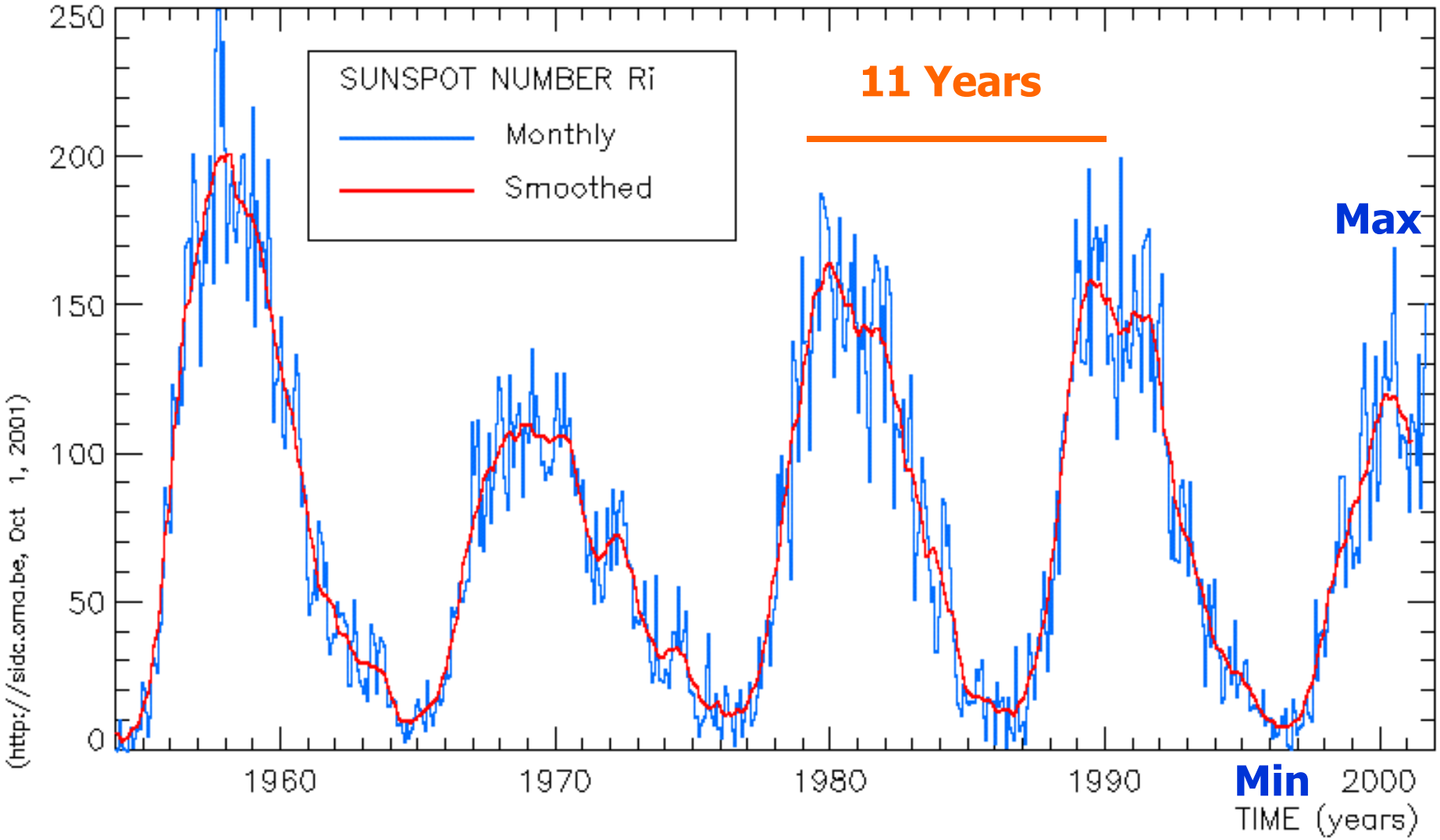
- An overview of the results of this study is presented here.

Data Set

- Study of plasma and IMF data from near Earth spacecraft (IMP, Wind, ACE).
- White-light, EUV and photospheric magnetic field observations from SOHO.

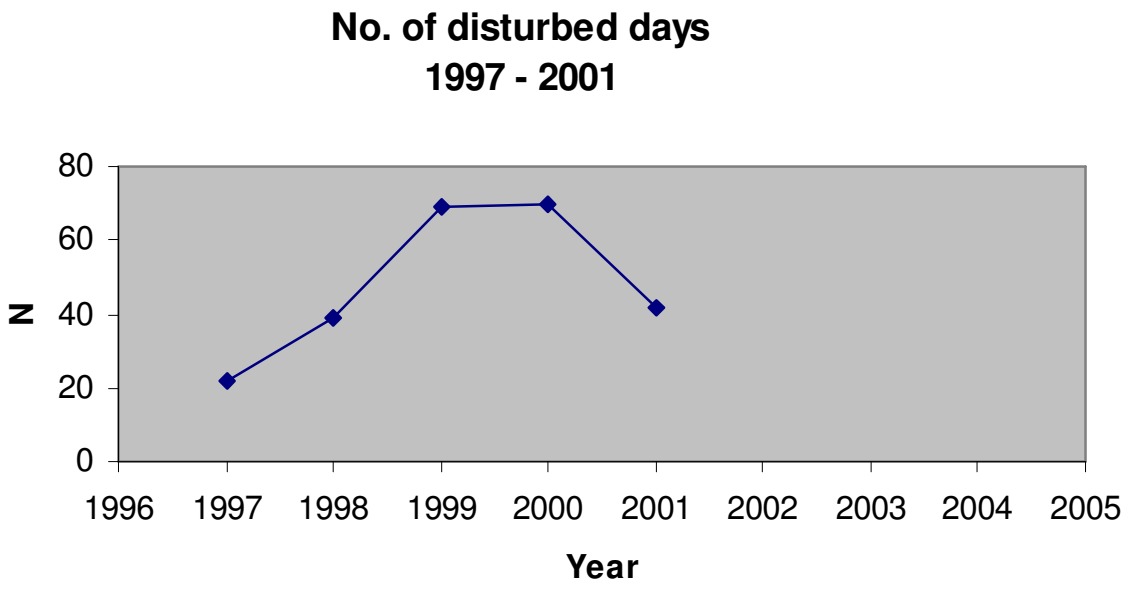
Solar wind plots courtesy A. Dmitriev.

The Current Solar Cycle



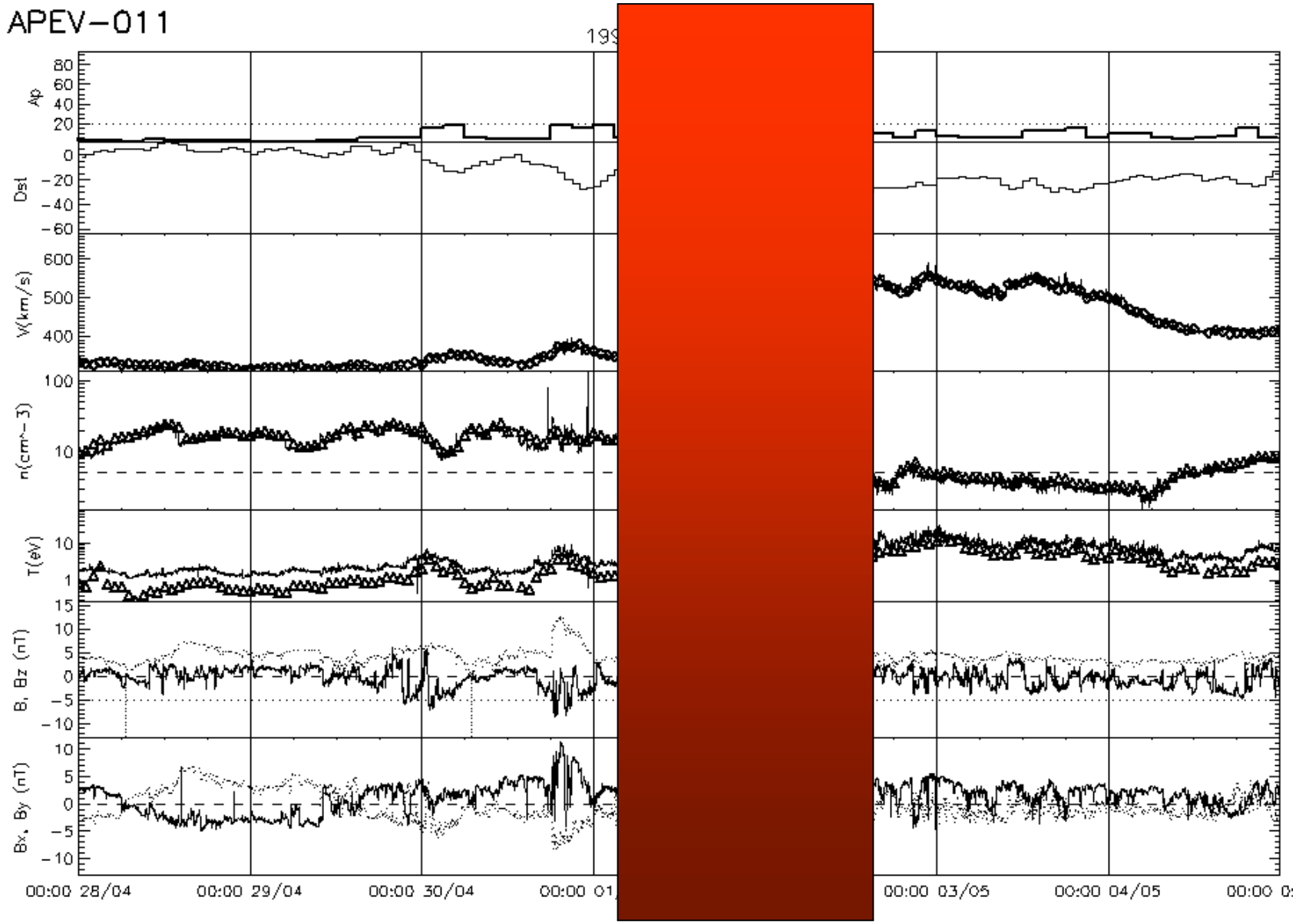
Total number of disturbed days 1997 - 2001

Year	Disturbed Days	Events
1997	22	21
1998	39	30
1999	69	38
2000	70	58
2001	42	36

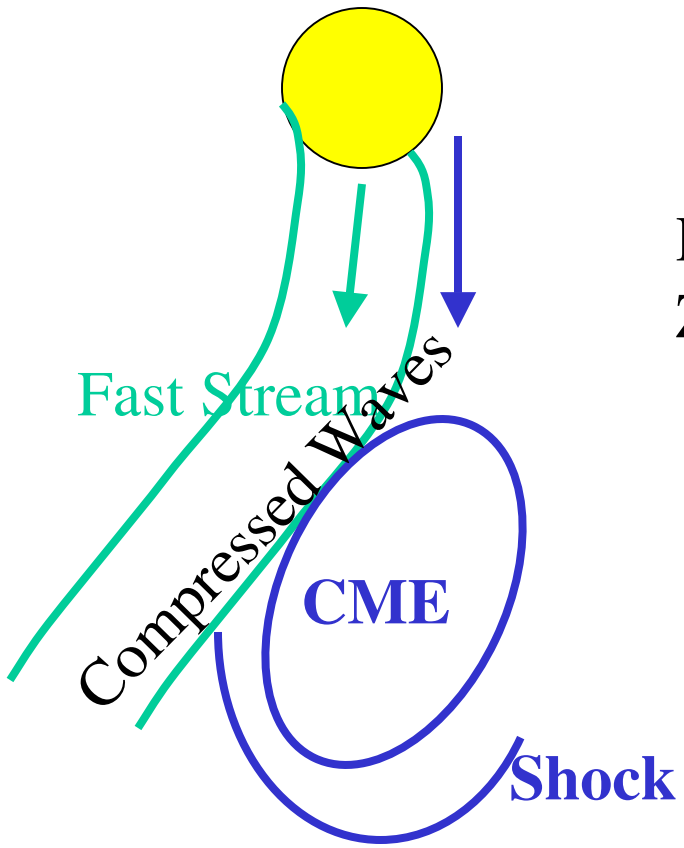


What were the interplanetary causes of geomagnetic storms with Ap > 20 in cycle 23 ?

Coronal hole flows – compression regions, field deflections, waves

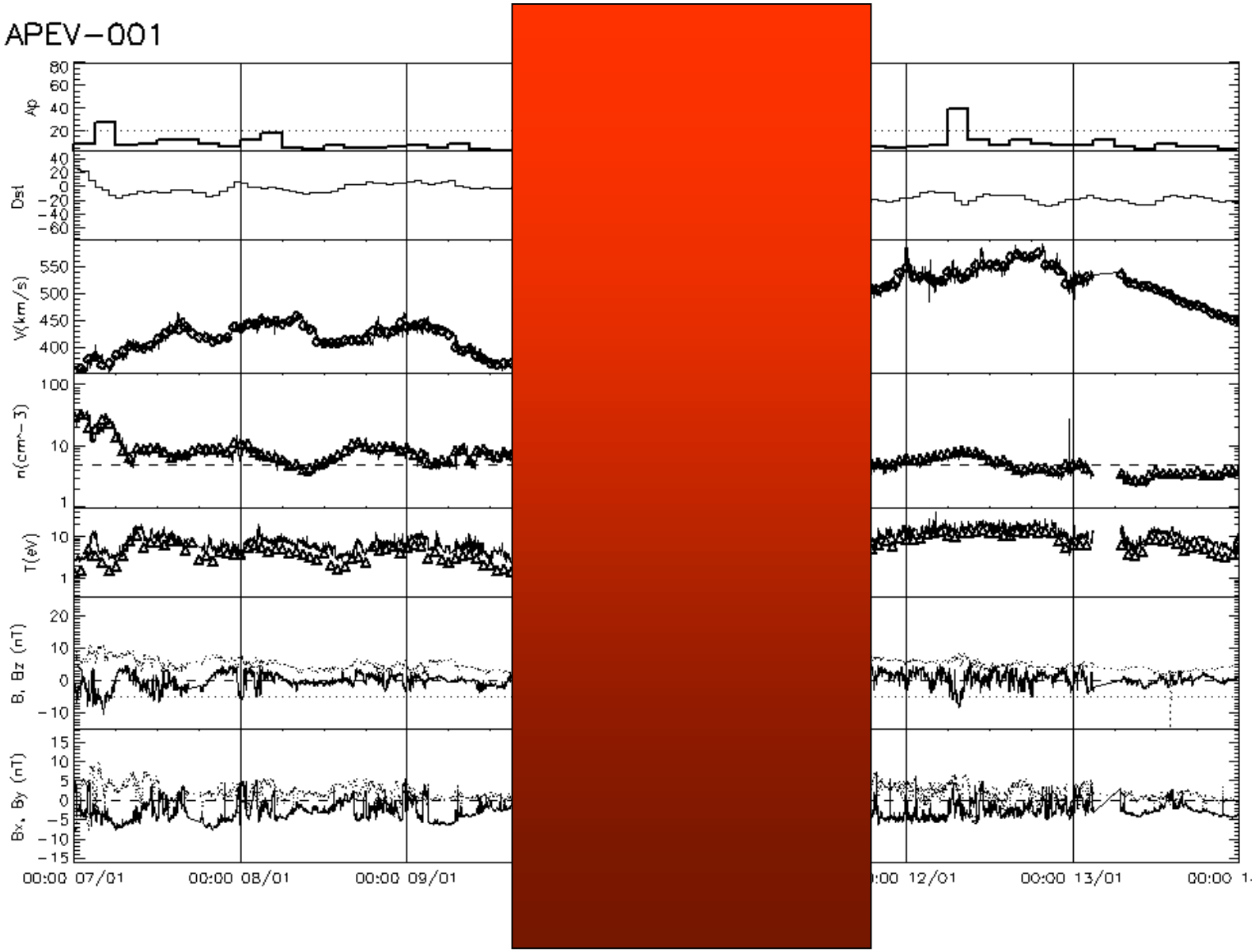


HSS/ICME Interaction
Swept-up ICMEs

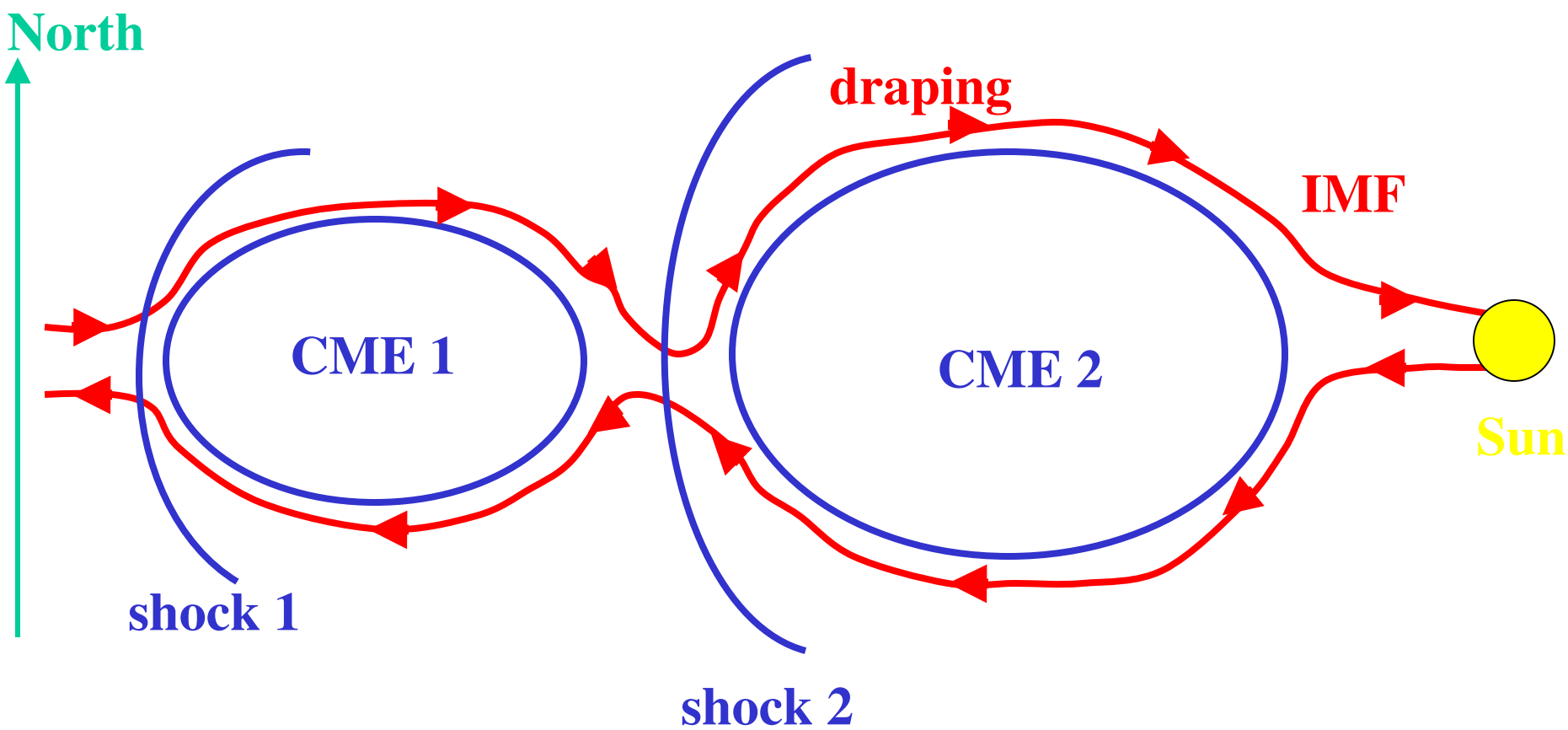


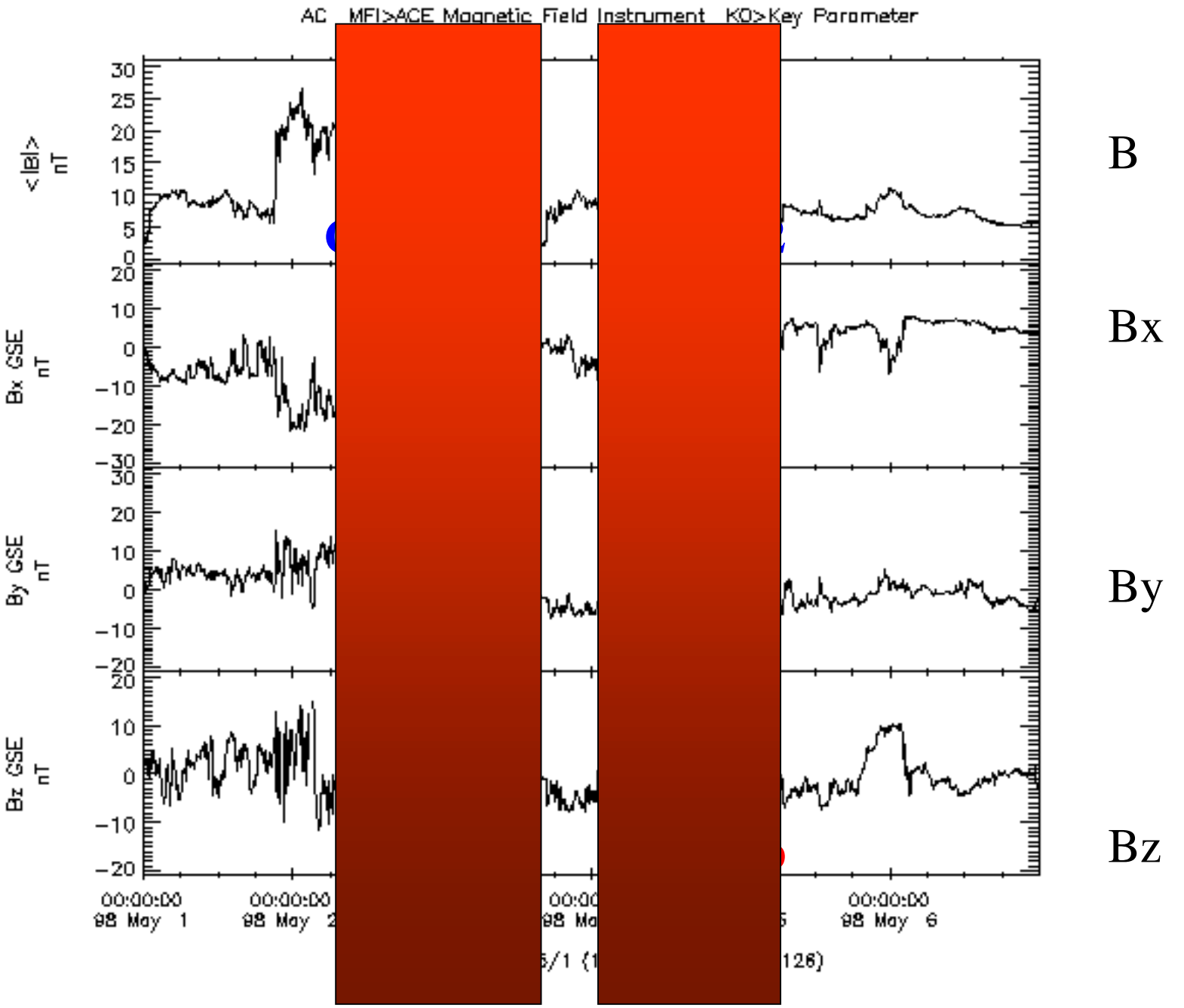
Refer to paper by J. Zhang et al., A.J., 2003

ICME/HSS interaction



Effects of Multiple CMEs

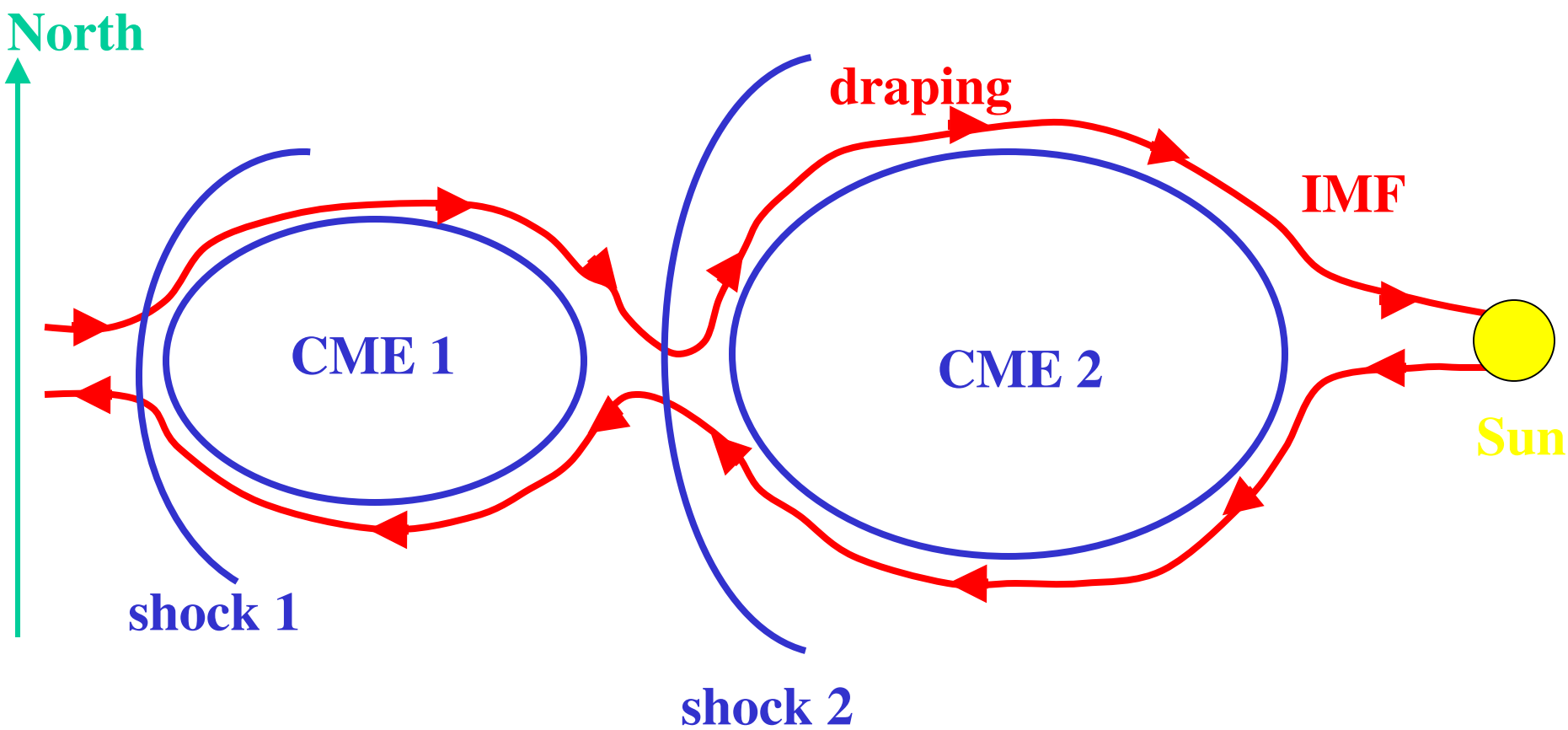




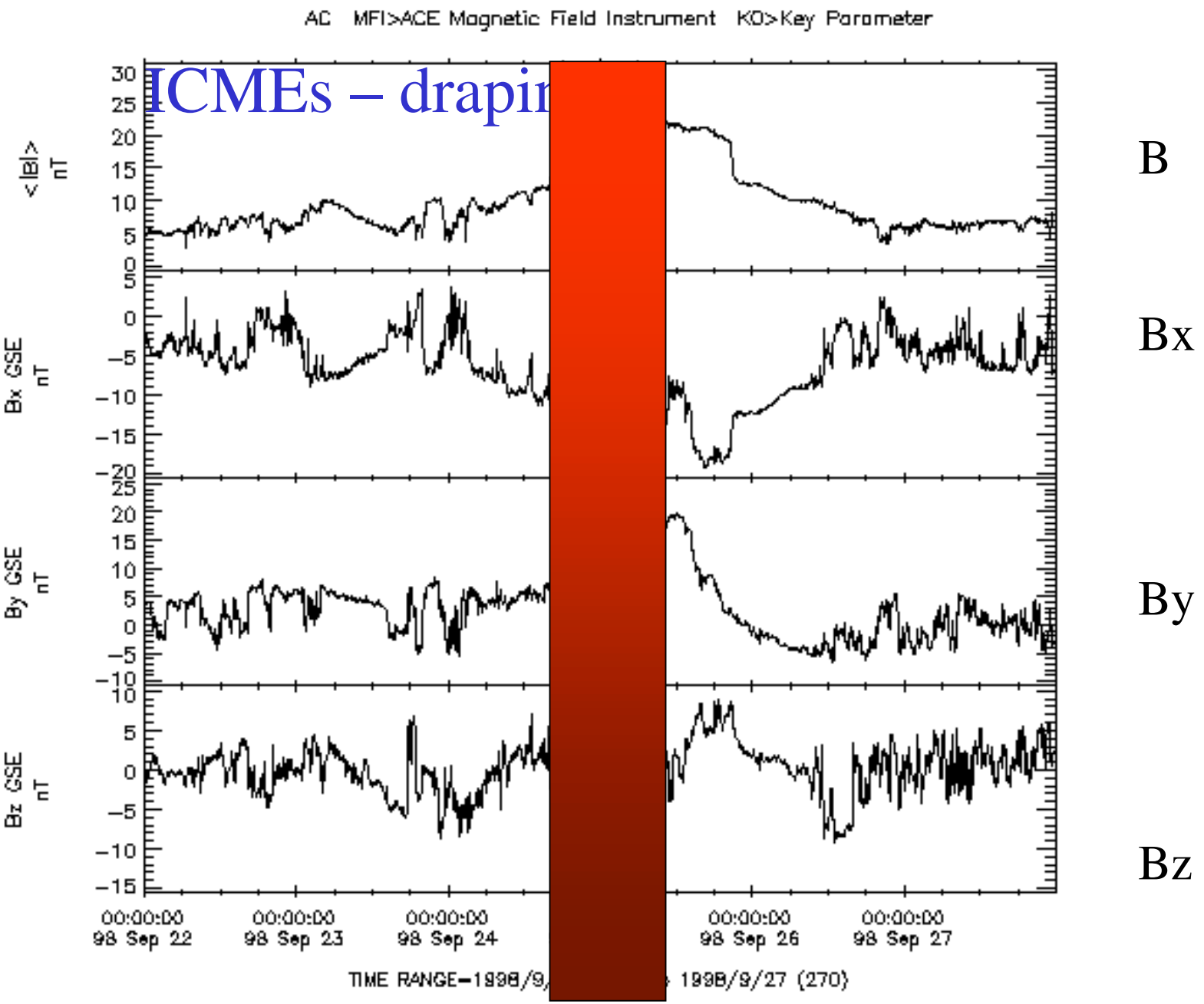
Please acknowledge data provider, N. Ness at Bartol Research Institute and CDAWeb when using this data.

Key Parameter and Survey data (labels K0,K1,K2) are preliminary browse data. Generated by CDAWeb on Thu Nov 2 10:57:18 2000

Effects of Multiple CMEs

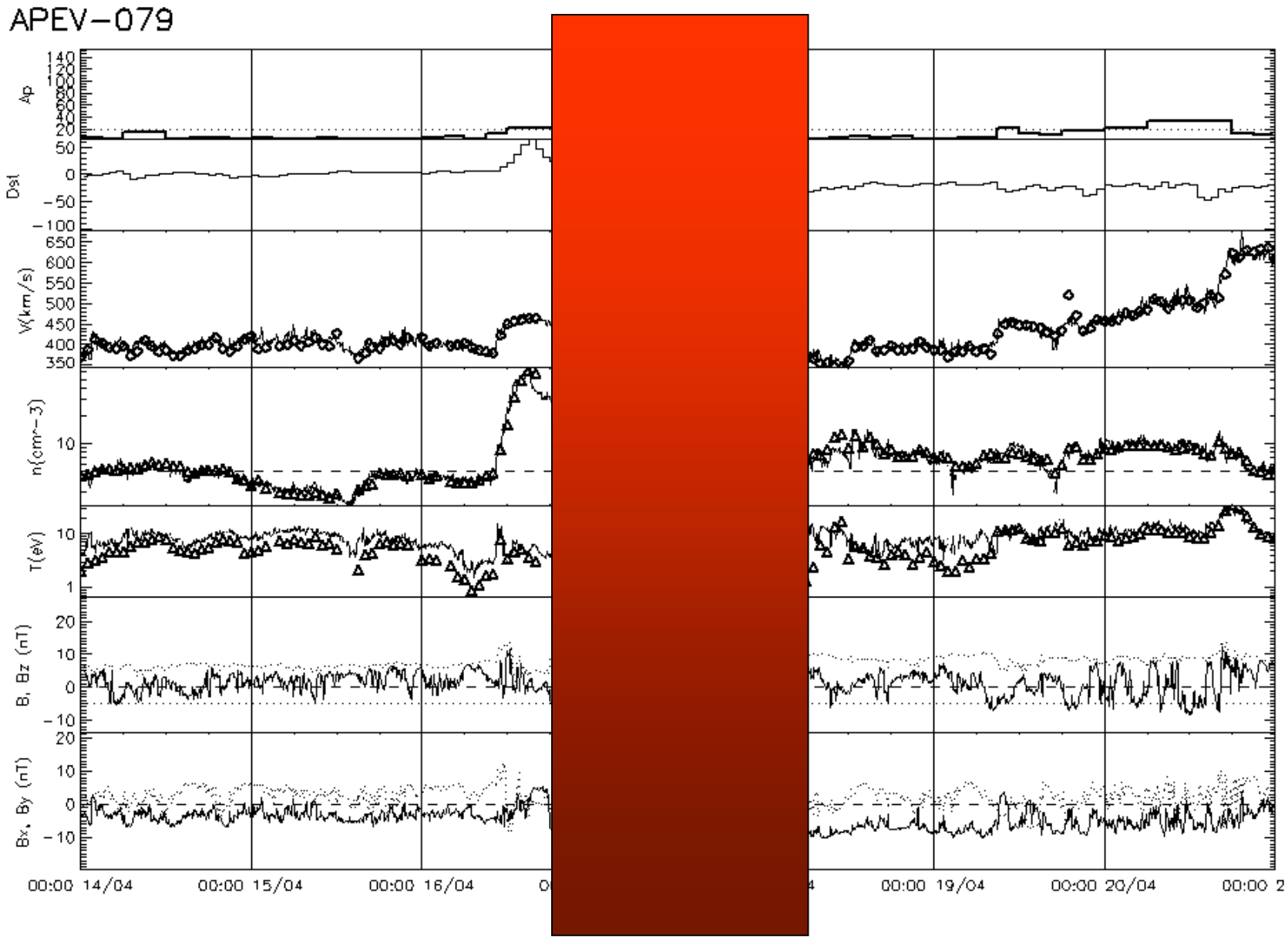


ICMEs – drapin

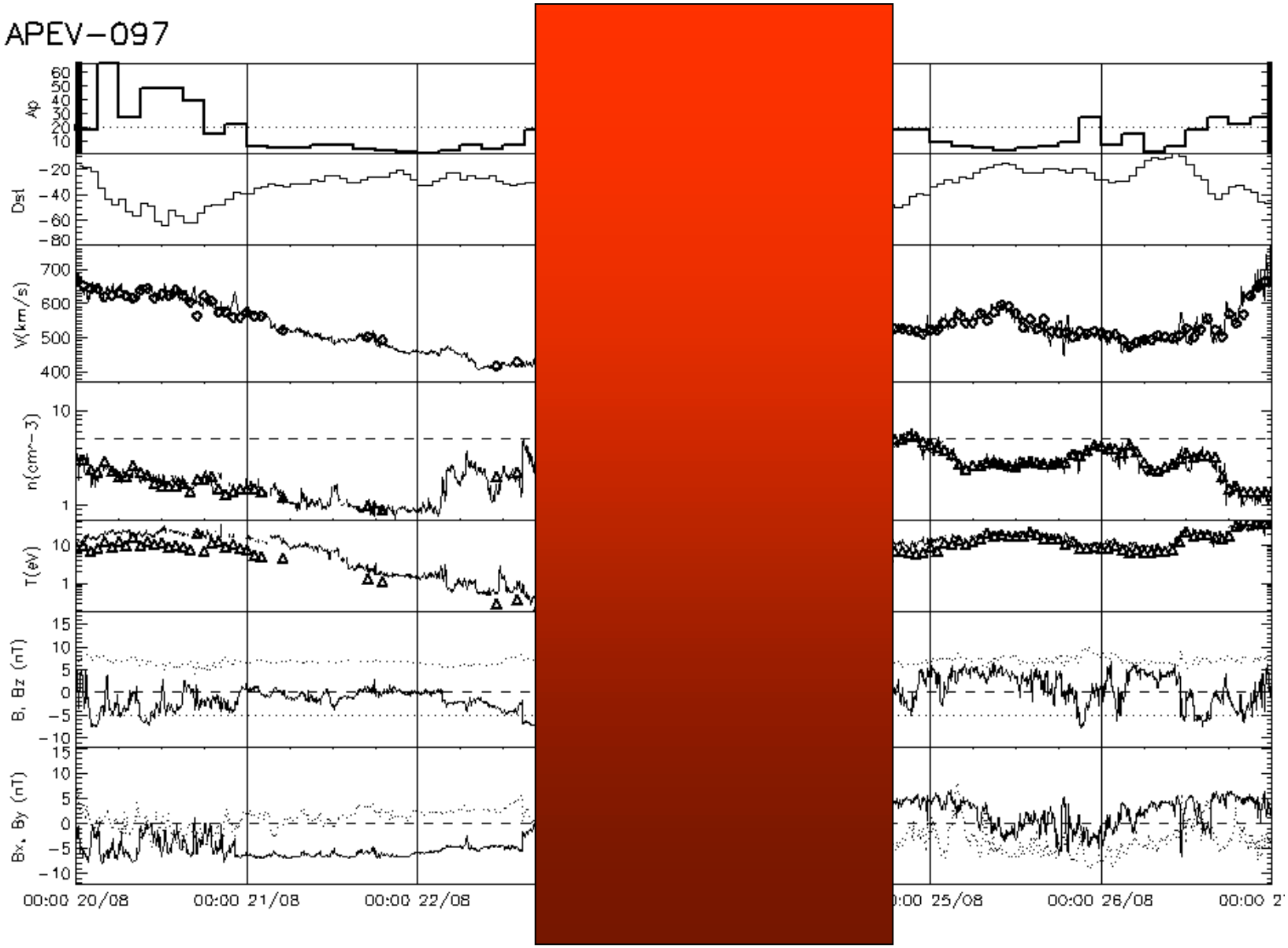


Please acknowledge data provider, N. Ness at Bartol Research Institute and CDAWeb when using this data.
Key Parameter and Survey data (labels K0,K1,K2) are preliminary browse data. Generated by CDAWeb on Thu Nov 2 11:54:40 2000

ICME – internal field (axis)



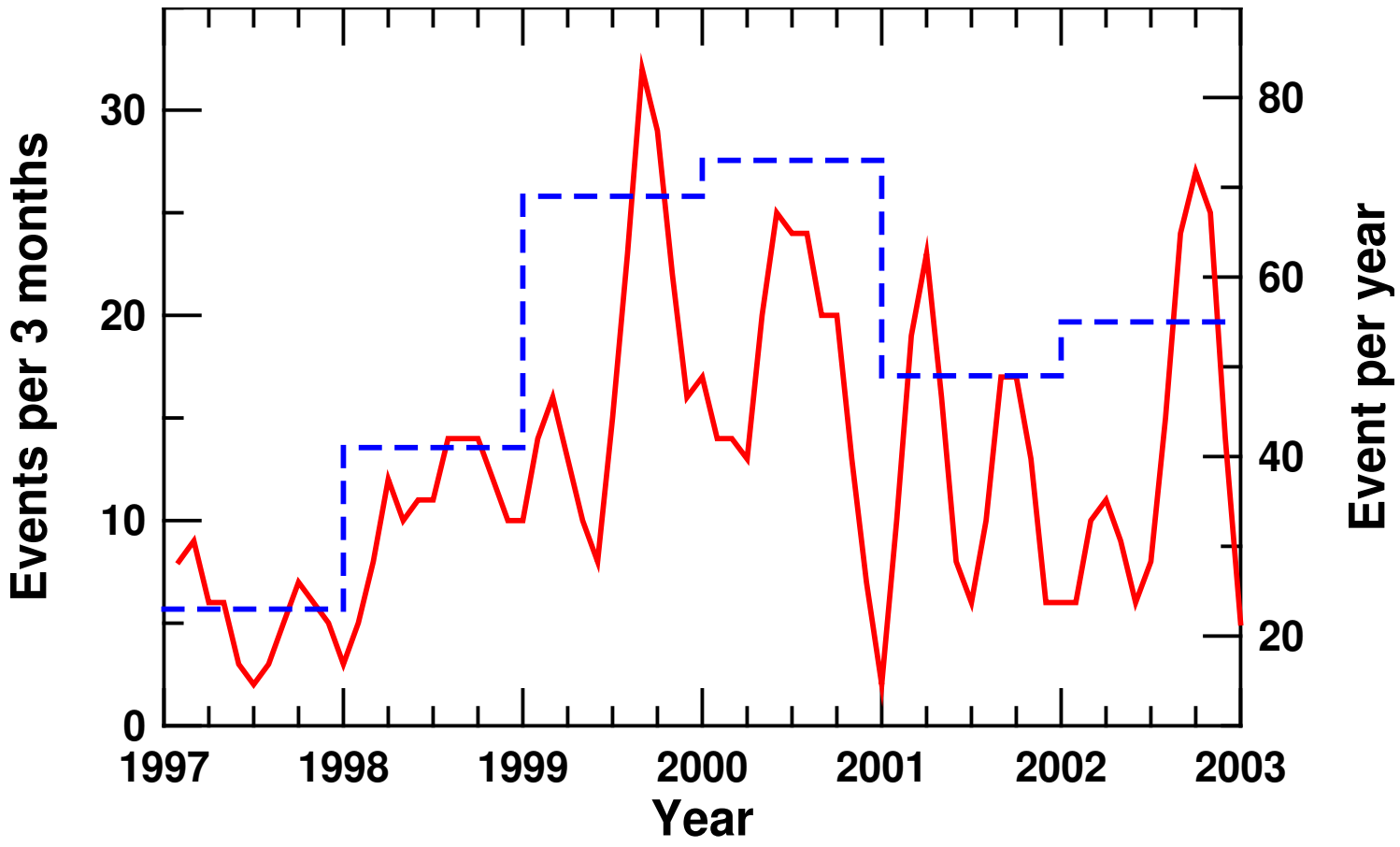
Slow wind soup with high plasma density & discontinuities near HCS



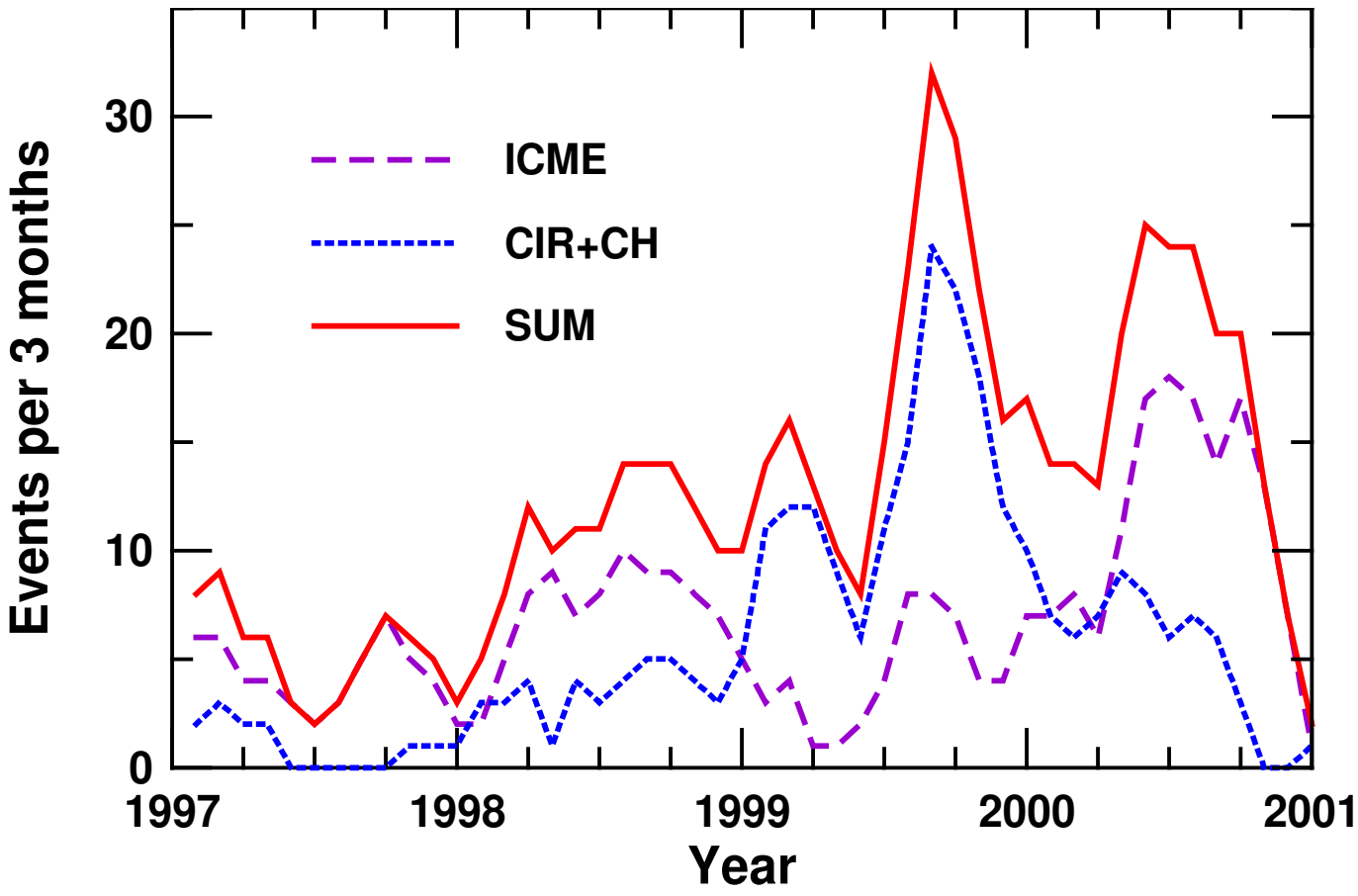
Causes for the disturbed days as inferred from inspection of the in situ data

1) Coronal hole flows – compression regions, field deflections, waves
2) Swept up ICMEs by CH flows
3) ICMEs – internal fields and draping
4) Multiple ICMEs
5) Slow, turbulent solar wind „soup“ (CMEs as sources ?) near HCS

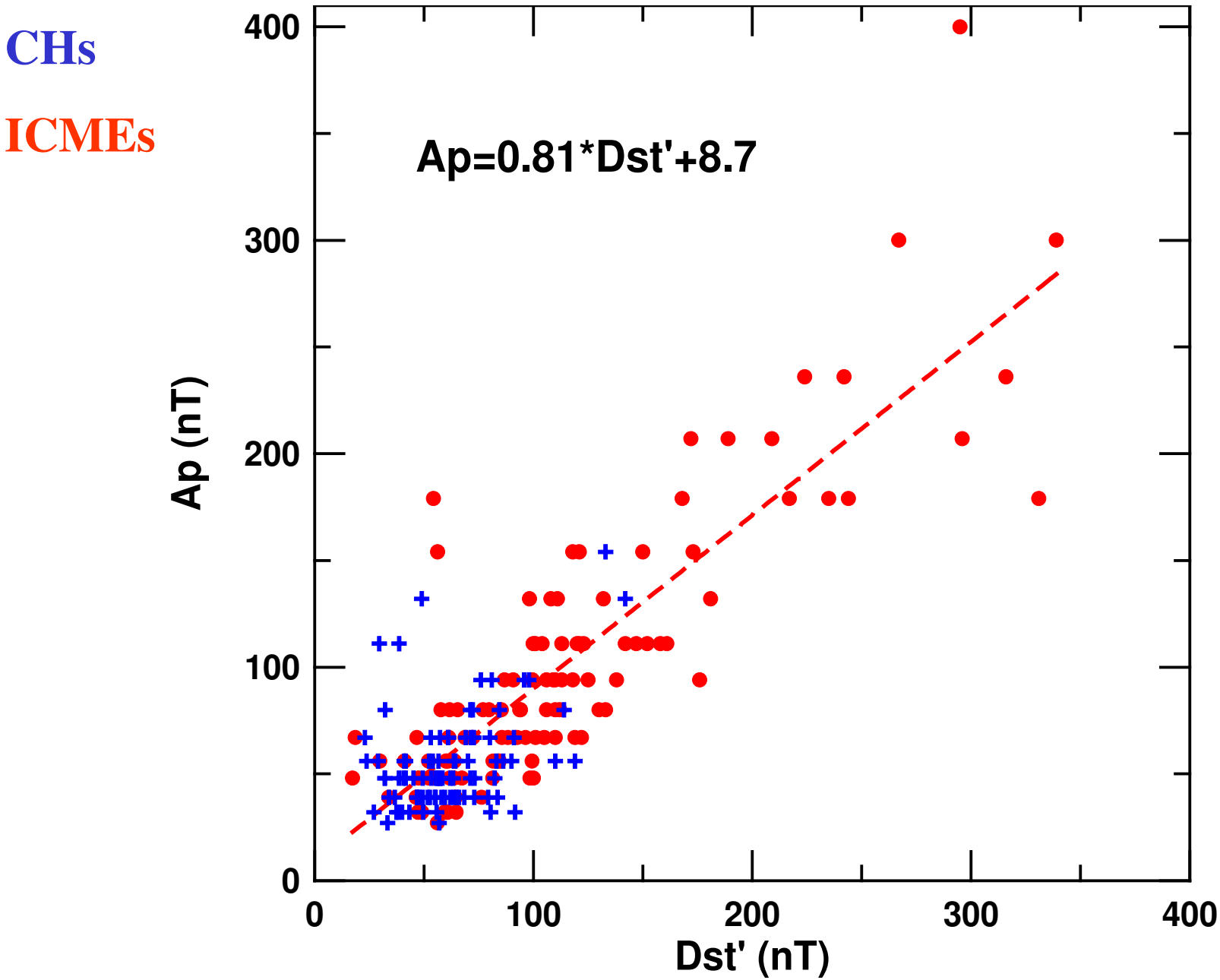
Statistical Overview



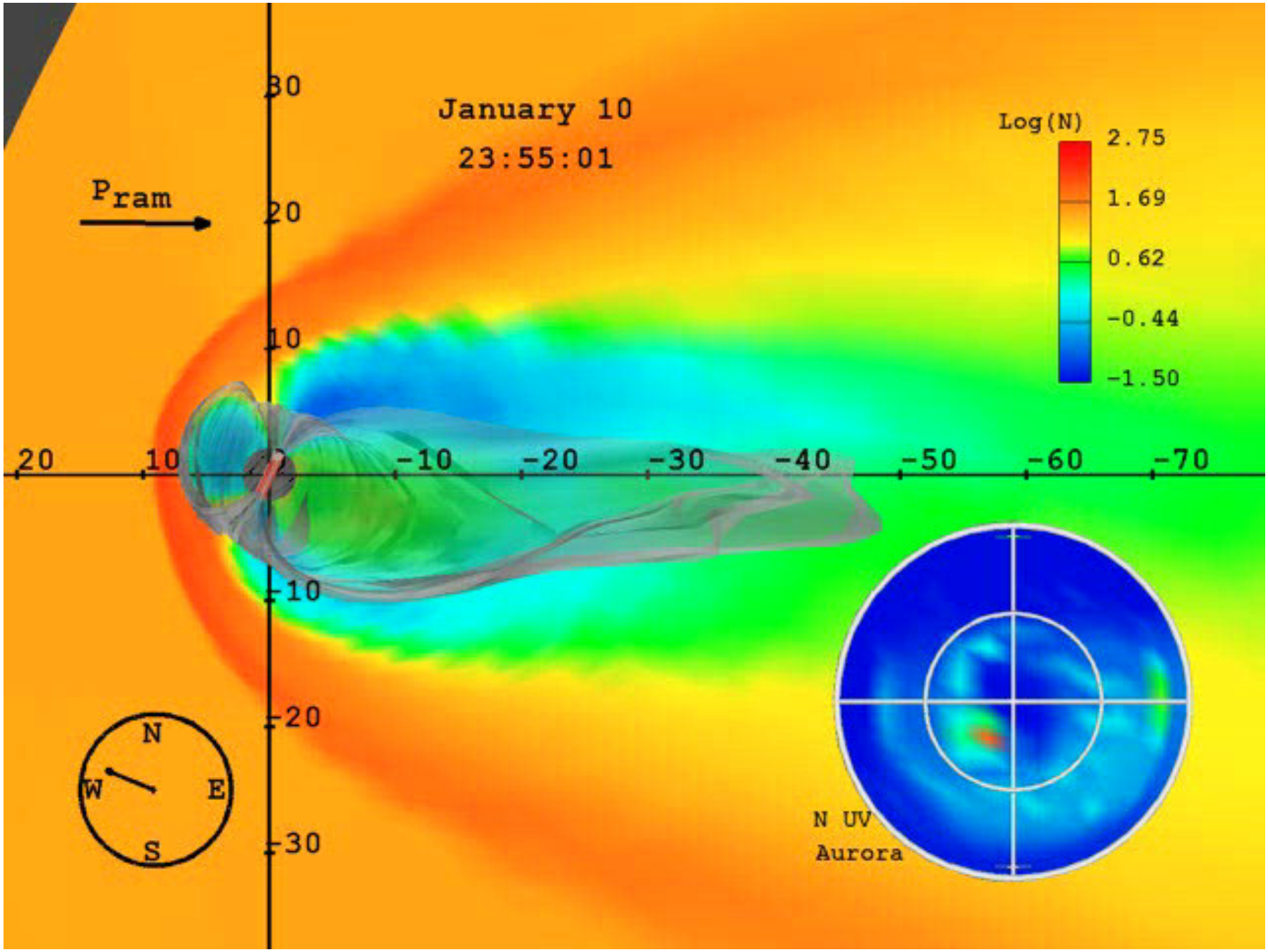
Courtesy A. Dmitriev

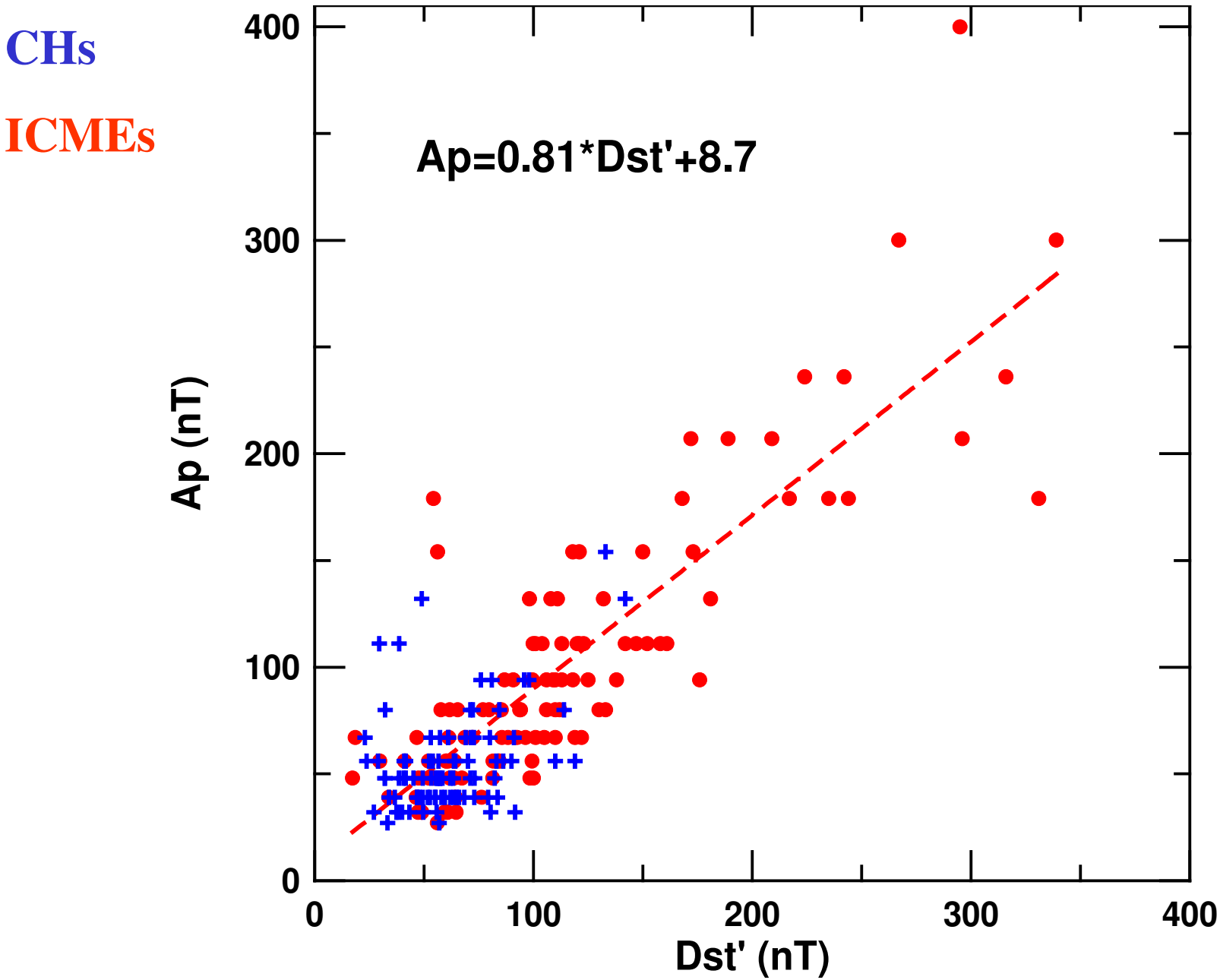


Courtesy A. Dmitriev



Courtesy A. Dmitriev

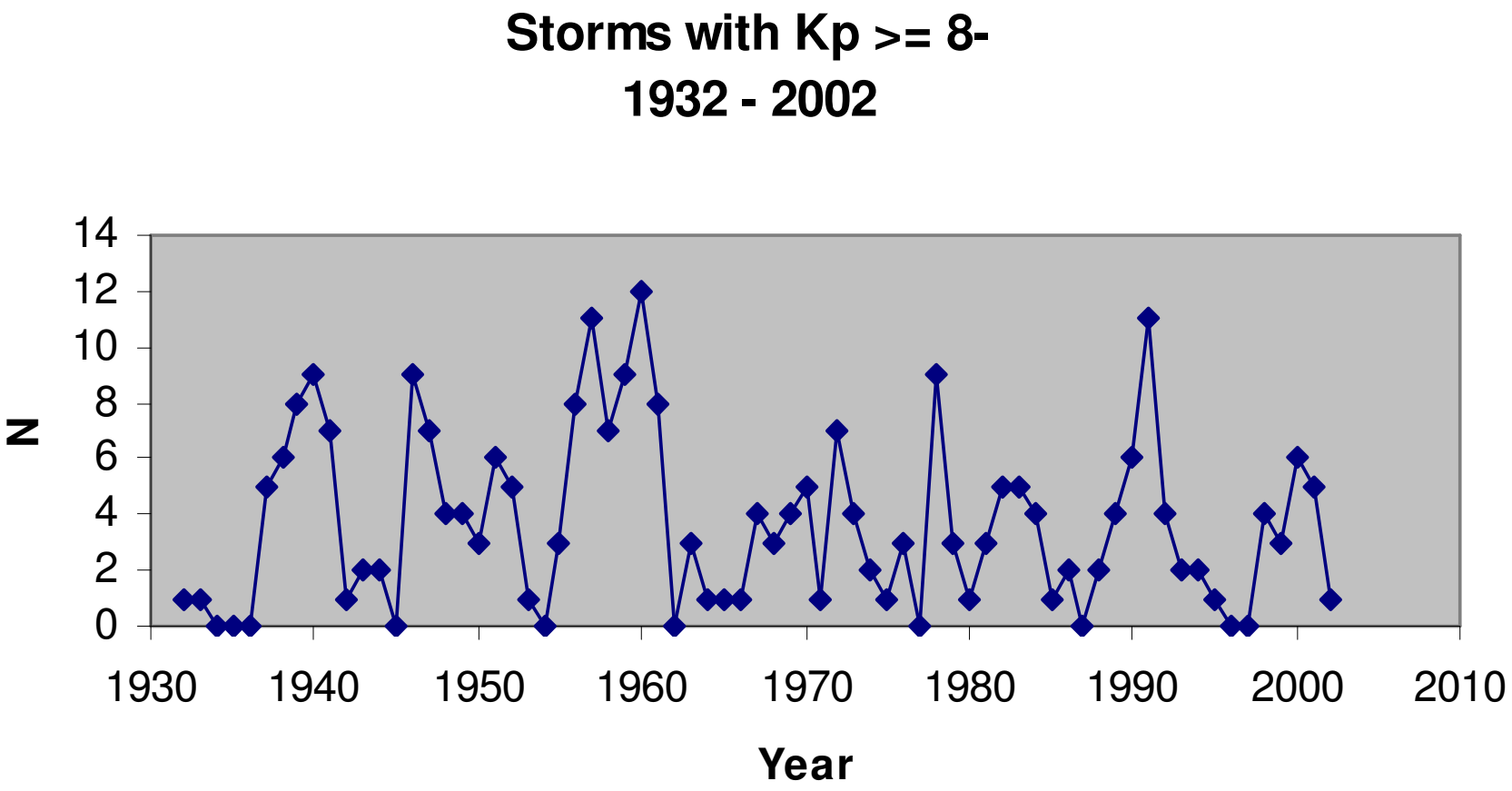

January 10
23:55:01
Pram
Log(N)
2.75
1.69
0.62
-0.44
-1.50
30
20
10
-10
-20
-30
20
10
-10
-20
-30
-40
-50
-60
-70
N
W
E
S
N UV
Aurora



Courtesy A. Dmitriev

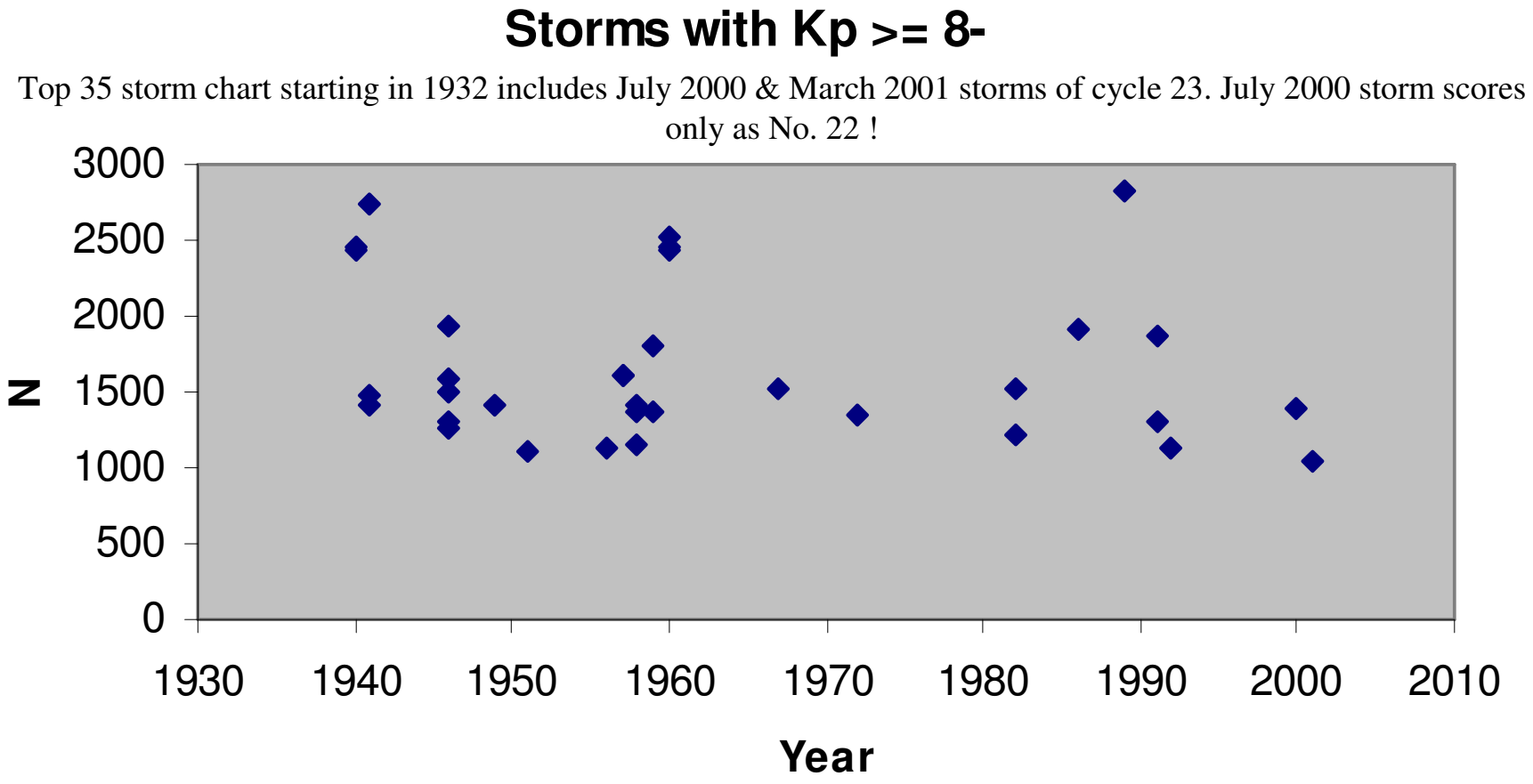
How strong were the storms in this cycle ?

General Overview on how Activity Compares with Previous Cycles



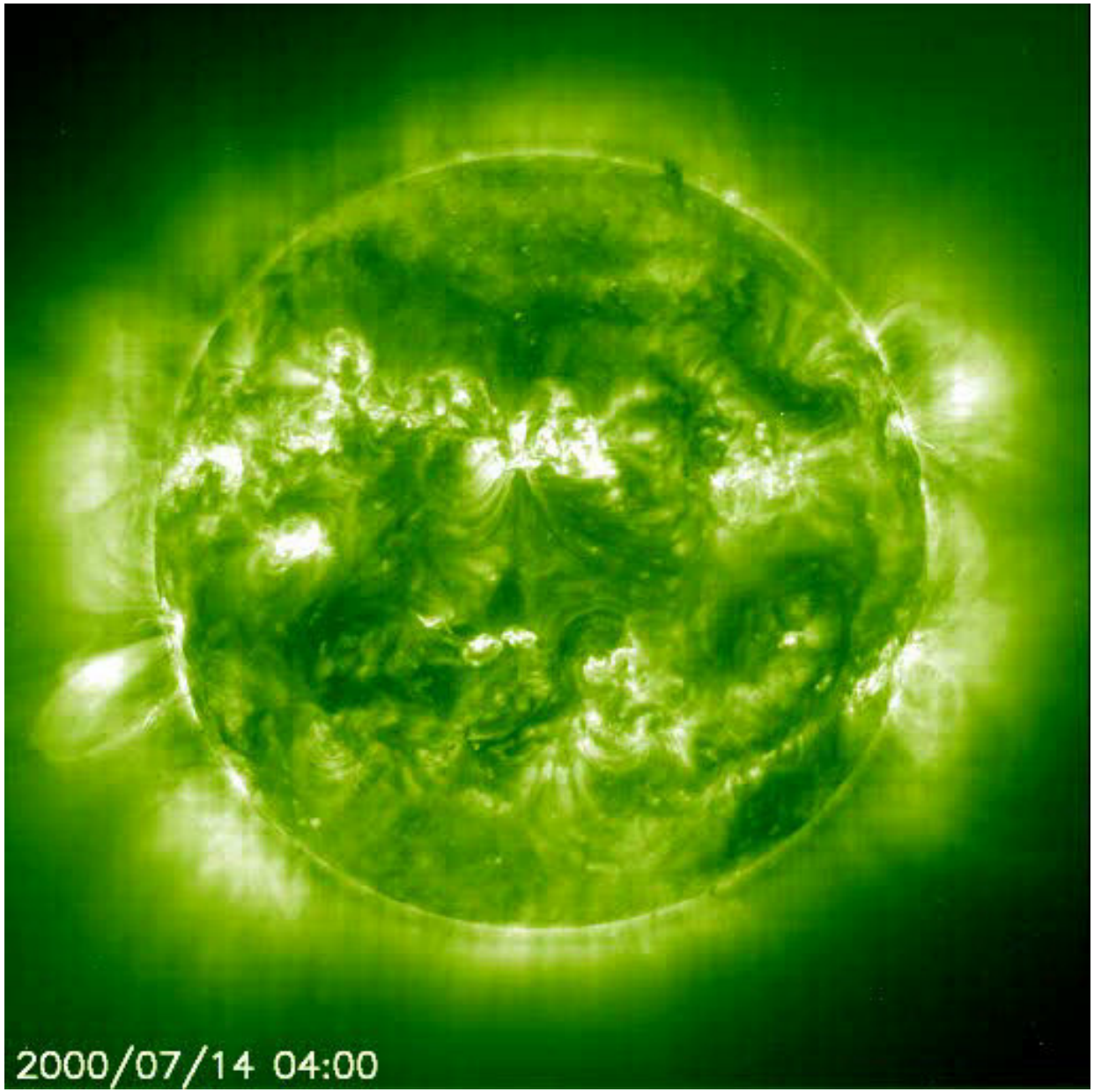
Note: If a Cycle is Moderate in Terms of the Number of Severe Storms it Does not Mean However, that there were No Outstanding Single Shots

The Strongest Storms – A Time History



Strongest Geomagnetic Storms (Kp-Values Added up in Single Events) Since 1932 – Note, that there were Major Solar Energetic Particle Events in 1972 ! For SEP events Statistics are Different.

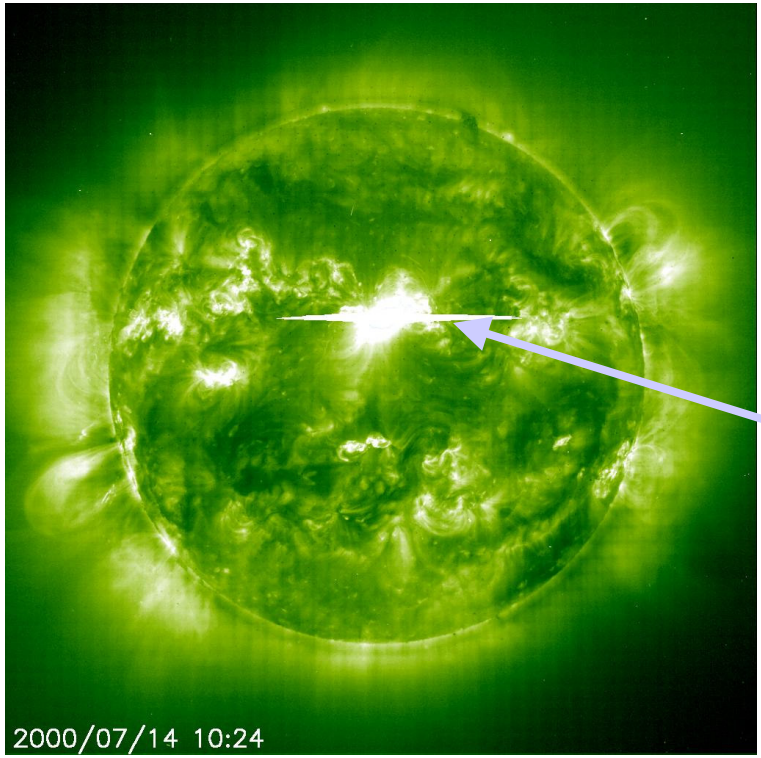
The EUV Sun on July 14, 2000: A Major Flare (X6) !

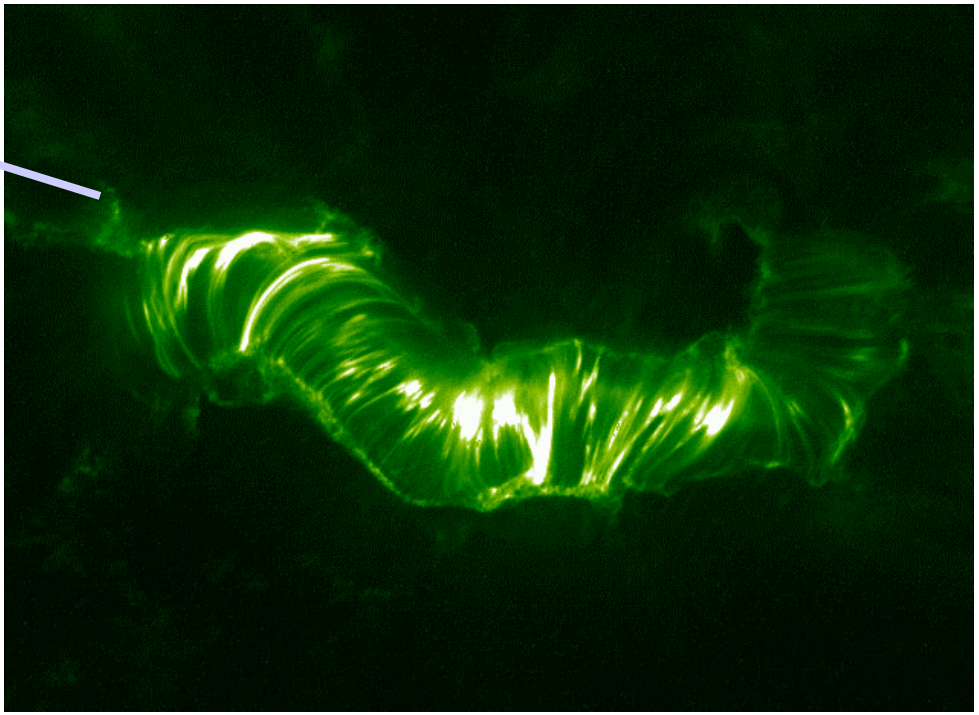


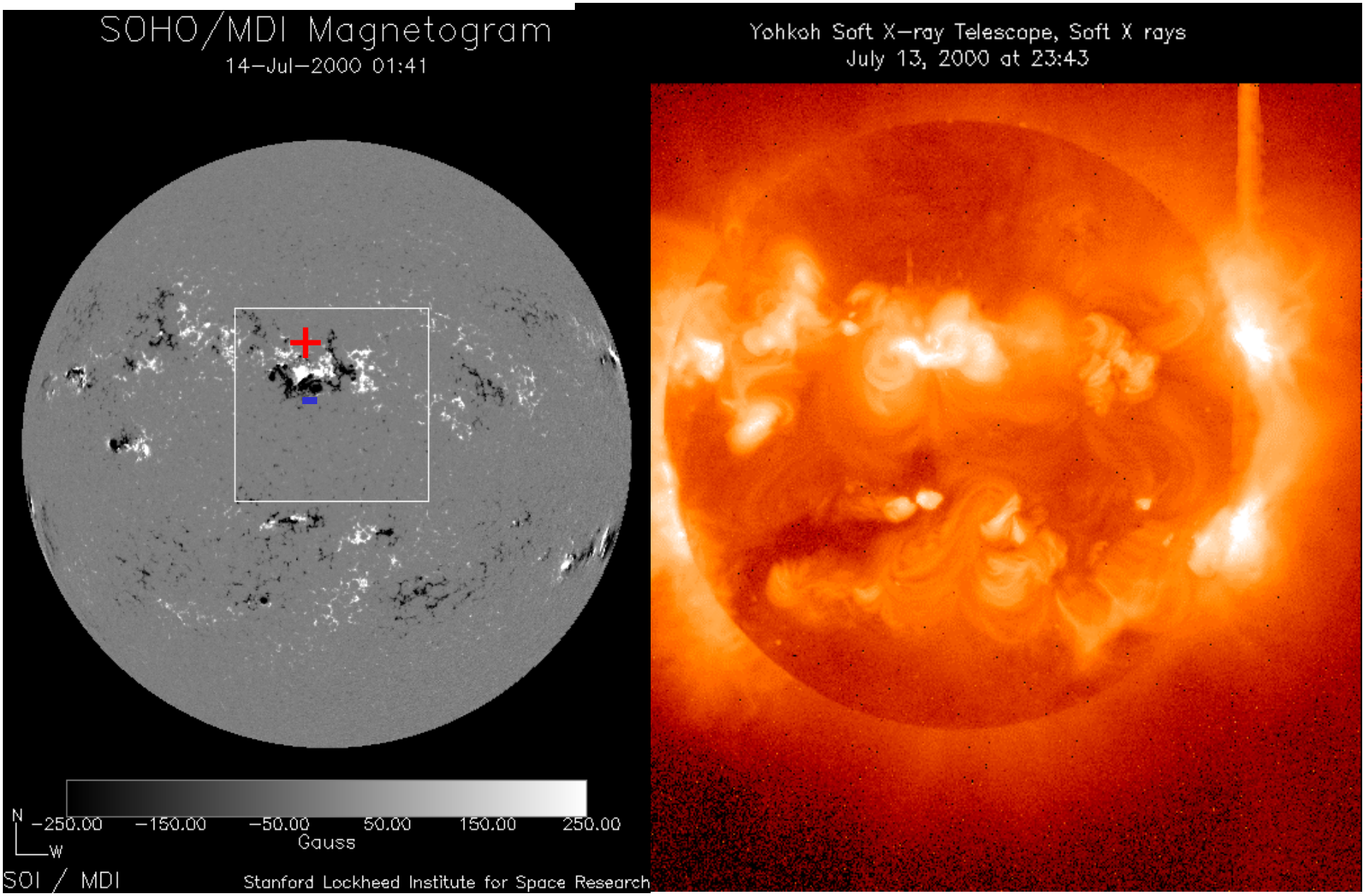
SOHO/EIT

195 Å

SOHO/EIT und TRACE Beobachtungen

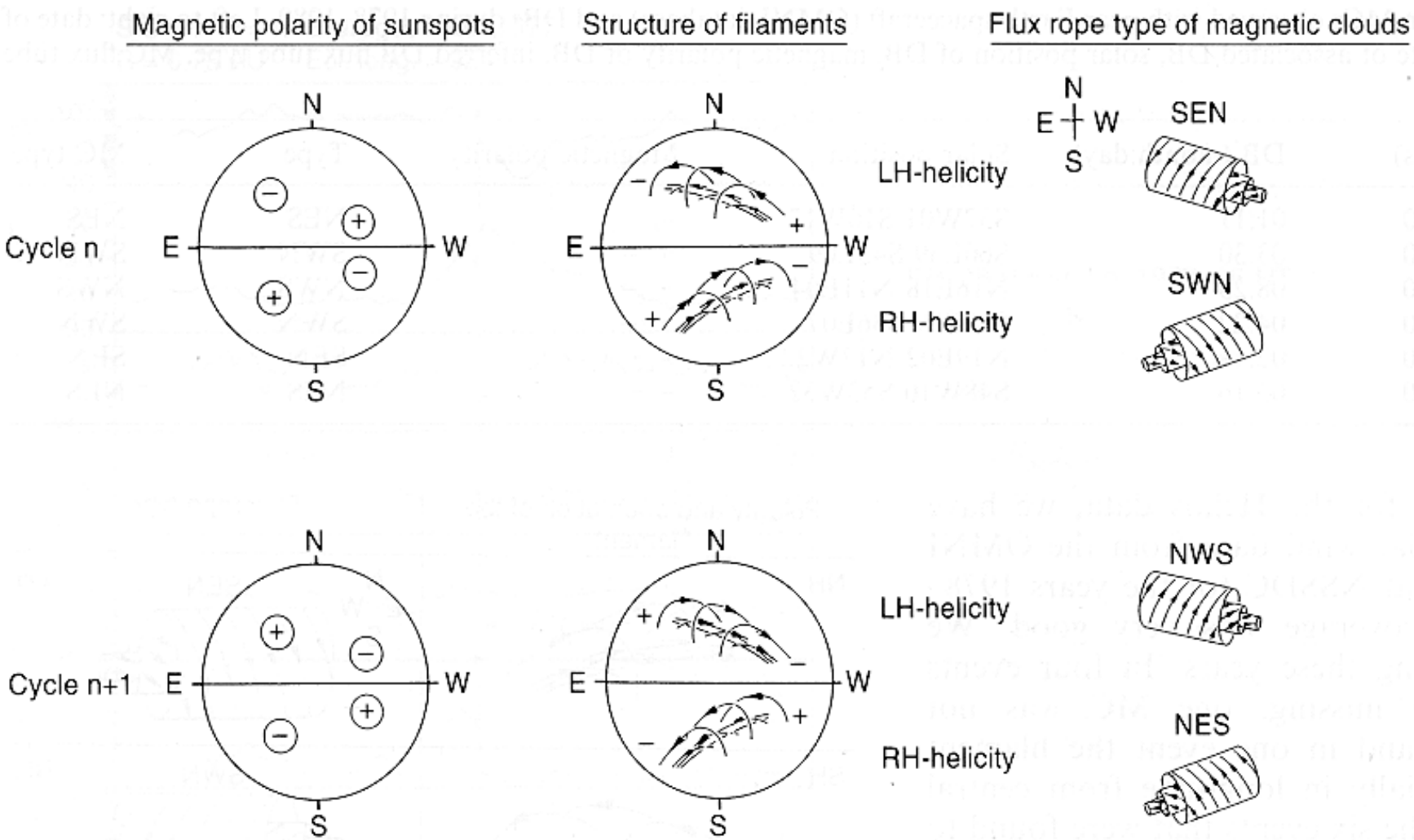






Expected flux-rope type: SEN (left-handed)

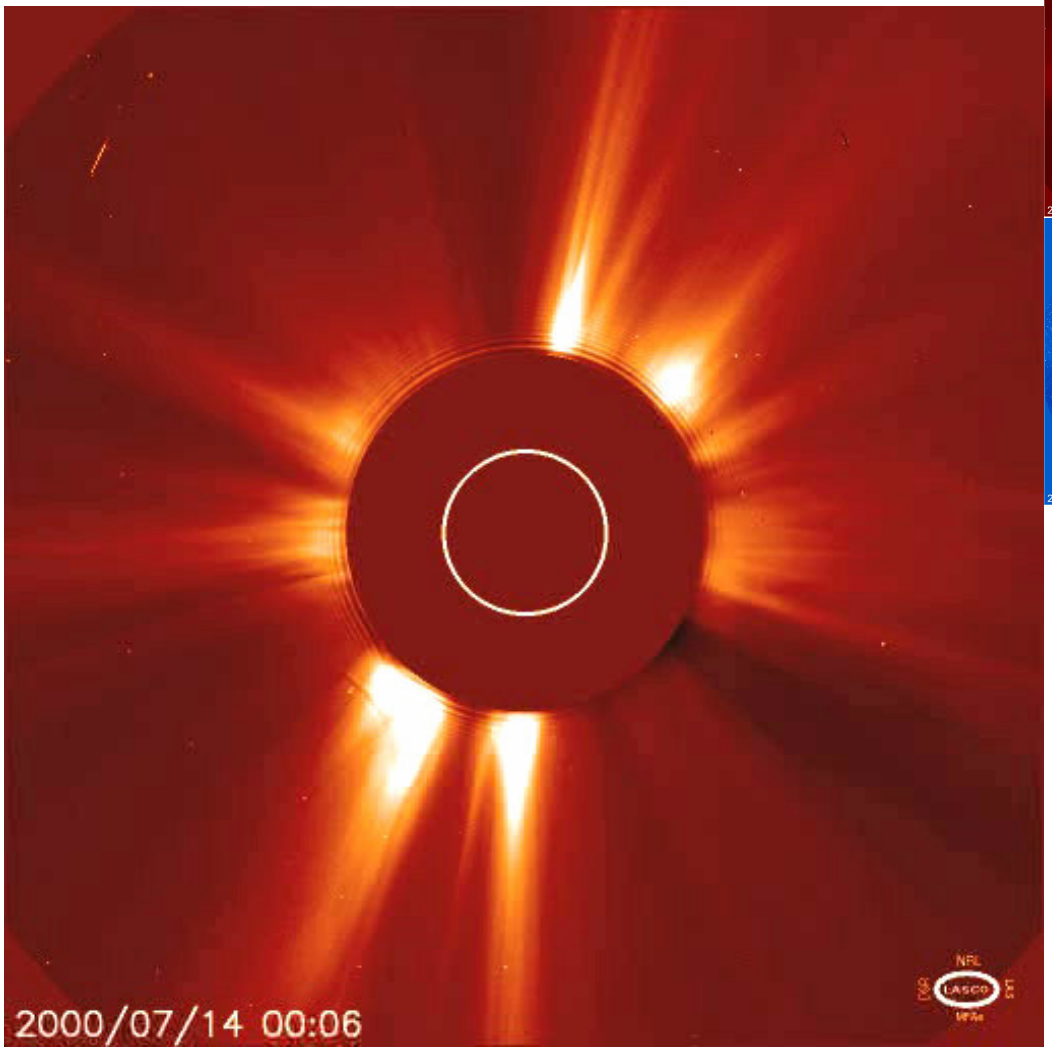
Solar cycle variation of the magnetic structures of filaments and helical flux rope CMEs in the solar wind

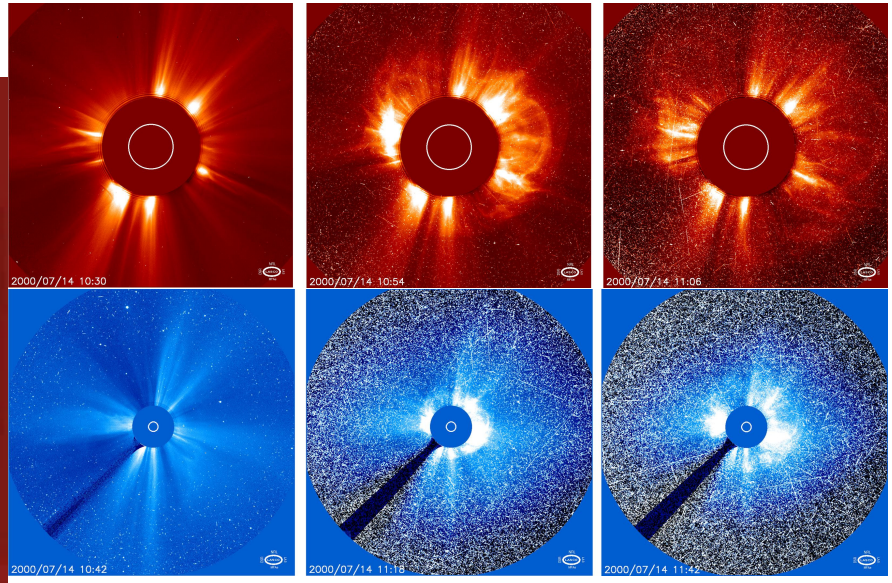


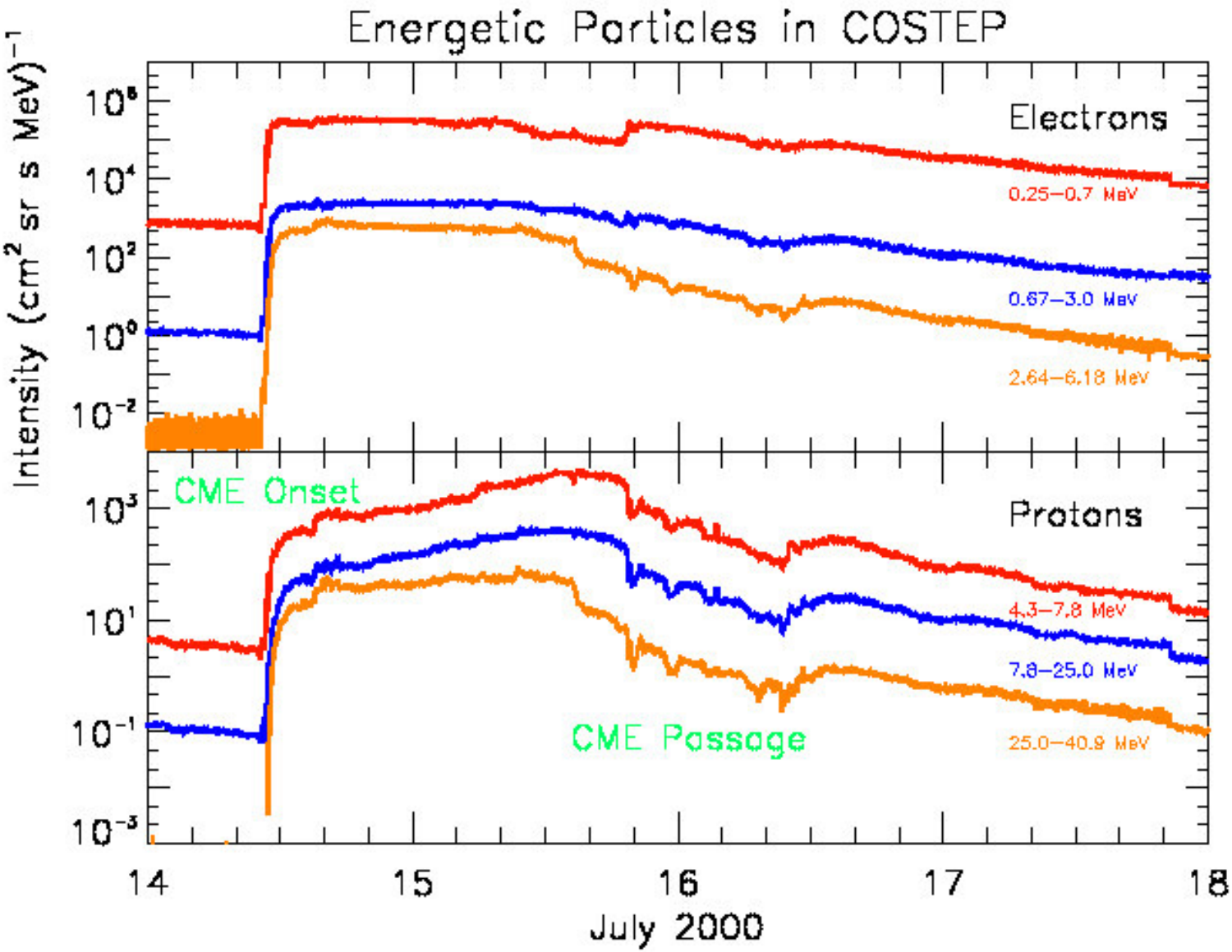
Involves findings on filament structures by *Martin* and *Rust*

Bothmer und Rust, 1997; Bothmer and Schwenn, 1998

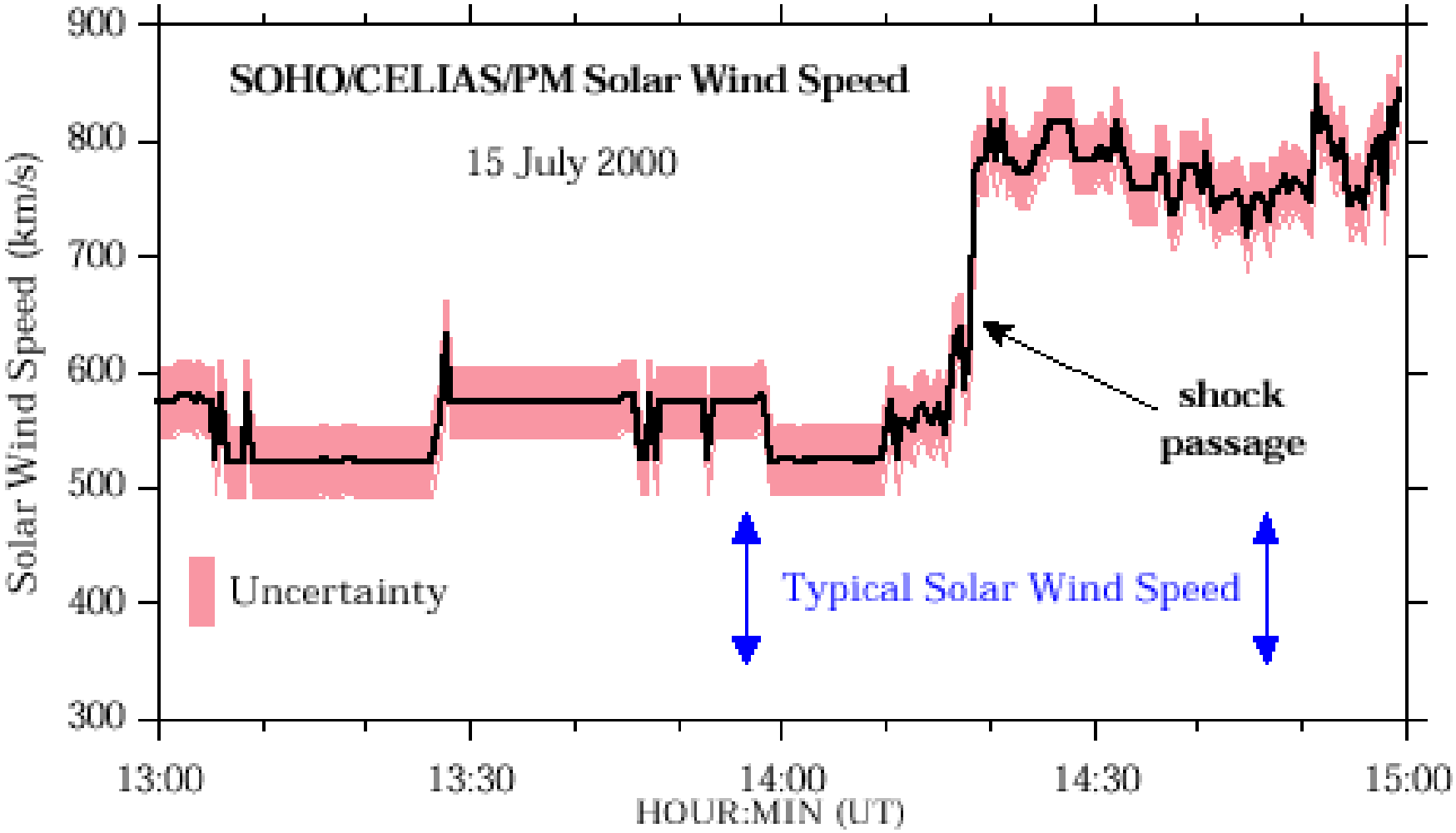
Der stärkste Sonnensturm des jetzigen Zyklus

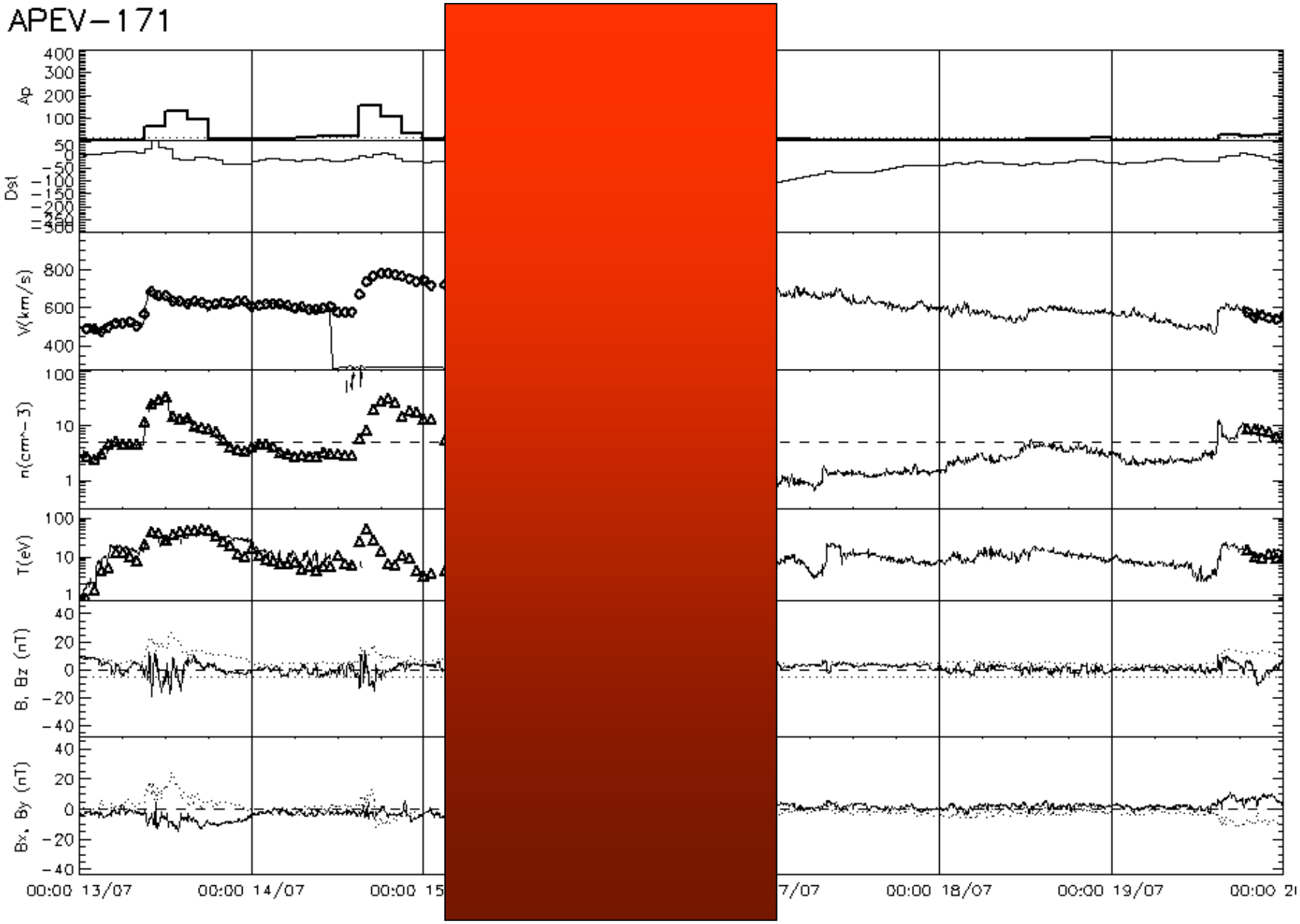





Energetic Particles in COSTEP
Intensity (cm^2 sr s MeV)$^{-1}$
Electrons
0.25–0.7 MeV
0.67–3.0 MeV
2.64–6.18 MeV
CME Onset
Protons
4.3–7.8 MeV
7.8–25.0 MeV
25.0–40.9 MeV
CME Passage
14
15
16
17
18
July 2000

Shock Wave in the Solar Wind on July 15, 2000




APEV−171
Ap
Dst
V(km/s)
n(cm^-3)
T(eV)
B, Bz (nT)
Bx, By (nT)
00:00 13/07
00:00 14/07
00:00 18/07
00:00 19/07

Summary

- Cycle 23 was a very moderate one in terms of space storms

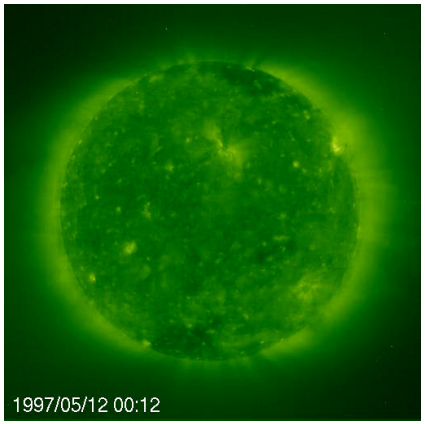
- The identified sources of geomagnetic storms in this cycle were:

1) Coronal hole flows – compression regions, field deflections, waves
2) Swept up ICMEs by CH flows
3) ICMEs – internal fields and draping
4) Multiple ICMEs
5) Slow, turbulent solar wind „soup“ (CMEs as sources ?) near HCS

- Multiple ICMEs and their interactions played the most crucial role for space weather in cycle 23.
- Peak activity was reached in 1999 and 2000 with surprisingly many, but weak in magnitude, CH flows in 1999 whereas 2000 was ICME dominated.
- In 2001 activity declined. ICMEs still were the dominat source of geomagnetic storms.

Conclusion

- Any reliable forecast of space storms has to take into account heliospheric & magnetospheric modulations complementary to the solar observations.

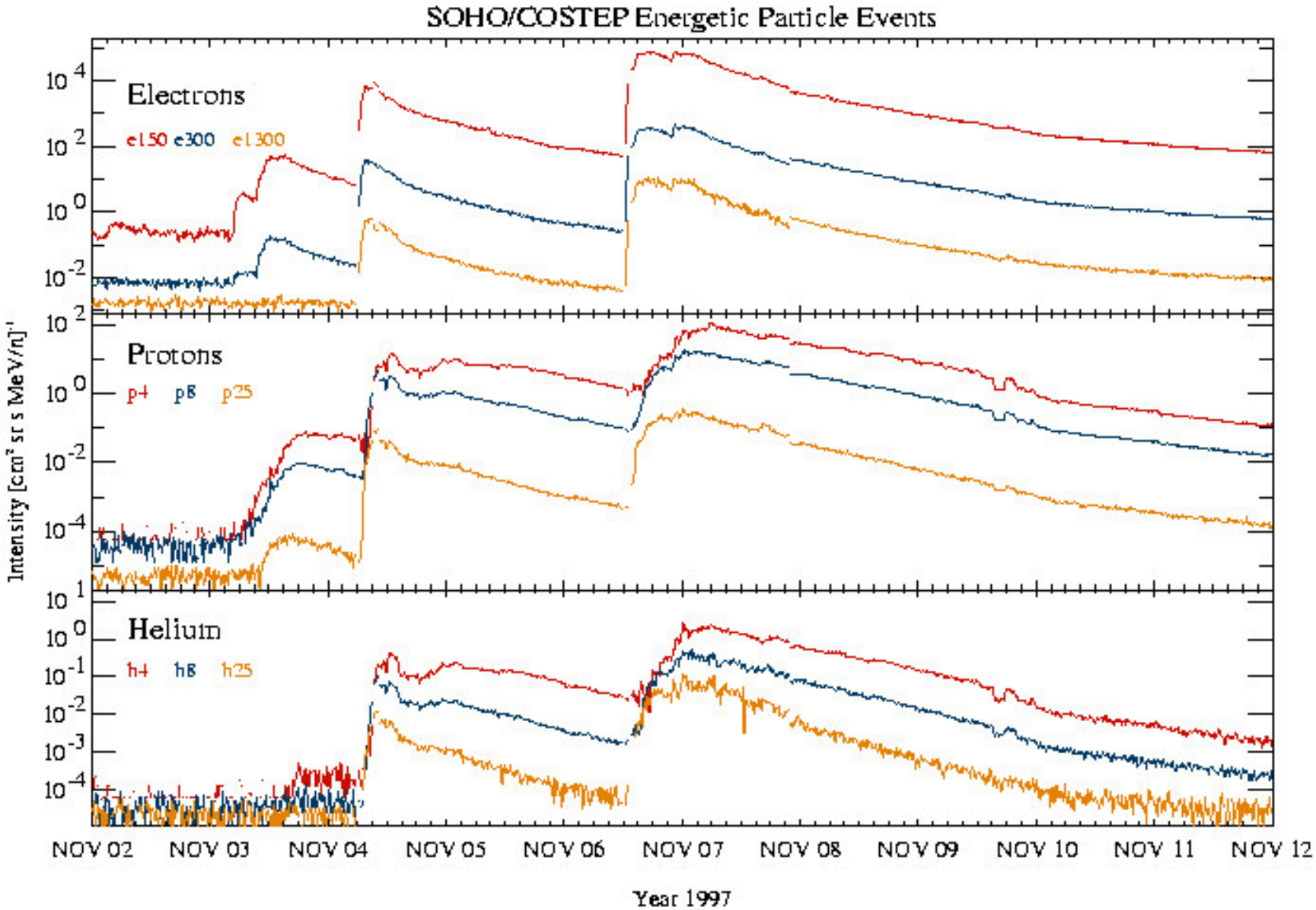


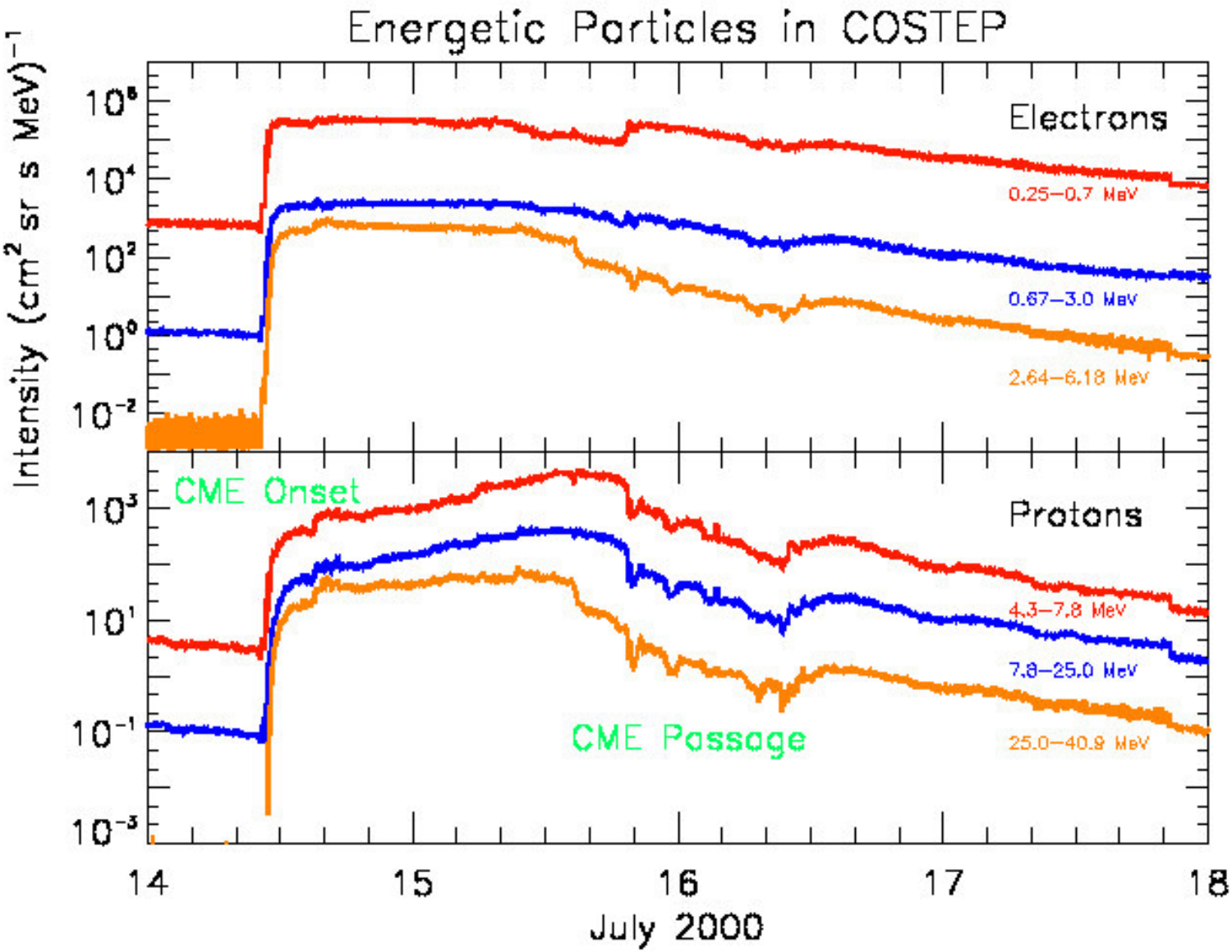
All events to look up at http://alpha.sinp.msu.ru/apev

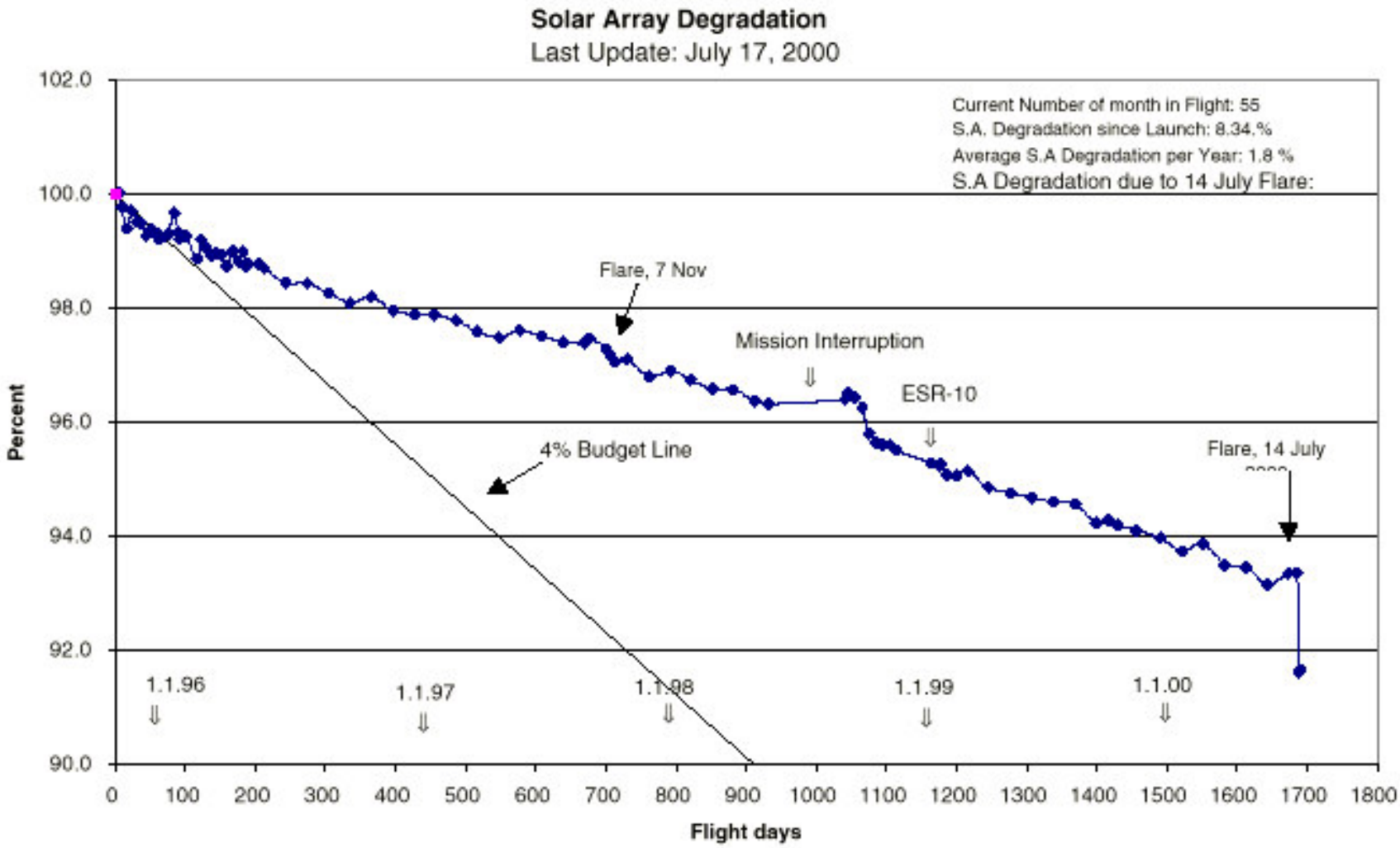
What about

SEP events ?

There is no major SEP event without an associated CME !


SOHO/COSTEP Energetic Particle Events
Electrons
e150 e300 e1300
Protons
p4 p8 p25
Helium
h4 h8 h25
Intensity [cm² sr s MeV/n]⁻¹
10 4
10 2
10 0
10 -2
10 2
10 0
10 -2
10 -4
10 1
10 0
10 -1
10 -2
10 -3
10 -4
NOV 02
NOV 03
NOV 04
NOV 05
NOV 06
NOV 07
NOV 08
NOV 09
NOV 10
NOV 11
NOV 12
Year 1997


Energetic Particles in COSTEP
Intensity (cm^2 sr s MeV)$^{-1}$
Electrons
0.25–0.7 MeV
0.67–3.0 MeV
2.64–6.18 MeV
CME Onset
Protons
4.3–7.8 MeV
7.8–25.0 MeV
25.0–40.9 MeV
CME Passage
14
15
16
17
18
July 2000


Solar Array Degradation
Last Update: July 17, 2000
Current Number of month in Flight: 55
S.A. Degradation since Launch: 8.34.%
Average S.A Degradation per Year: 1.8 %
S.A Degradation due to 14 July Flare:
Flare, 7 Nov
Mission Interruption
ESR-10
4% Budget Line
Flare, 14 July
1.1.96
1.1.97
1.1.98
1.1.99
1.1.00
Percent
Flight days
102.0
100.0
98.0
96.0
94.0
92.0
90.0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800

ASTROPHYSIK

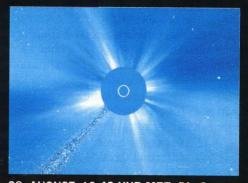
Stürme aus dem All

DIE ERUPTION vom 28. August (untere Bildhälfte rechts), aufgenommen vom japanischen Sonnenforschungssatelliten Yohkoh im Röntgenlicht

Die Sonne stößt in den nächsten Monaten gehäuft mächtige Gaswolken aus. Die Teilchenlawinen bedrohen Satelliten, Astronauten und die elektronische Infrastruktur

BEGINN EINES WELTRAUMSTURMS: EINE MÄCHTIGE ERUPTION AUF DER SONNE

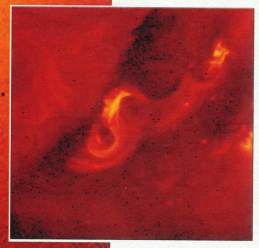
Der Wächtersatellit SOHO steht 1,5 Millionen Kilometer entfernt zwischen Erde und Sonne. Er nahm die Eruption im sichtbaren Licht auf. Die Sonnenscheibe ist abgedeckt, um die Korona sichtbar zu machen.



28. AUGUST, 13.42 UHR MEZ. Die Sonne strahlt normal, wie das Bild des Koronographen LASCO an Bord von SOHO zeigt

28. AUGUST, 22.18 UHR MEZ. Der Auswurf der Gasmassen (unten rechts) ist in Gang. Beginn der Eruption war 19.05 Uhr

29. AUGUST, 13.42 UHR MEZ. Die Plasmawolke hat sich von der Sonne gelöst. Magnetfelder schnüren das Gas zu einer Blase



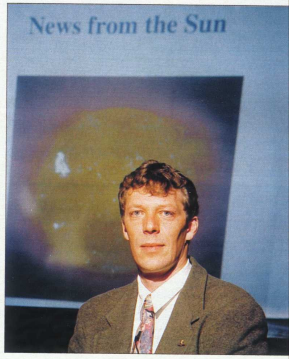
PROGNOSEFAKTOR
S-förmige Strukturen – Sigmoide – wie diese erscheinen meist vor Eruptionen auf der Sonne. Forscher wollen sie zur Frühwarnung nutzen. Sigmoide entstehen durch verdrillte Magnetfelder

Der Sturm im All kündigte sich zuerst durch einen Röntgenblitz an. Der Satellit GOES 8 der US-Umweltüberwachungsbehörde National Oceanic and Atmospheric Administration (NOAA) registrierte die Strahlung am Abend des 28. August dieses Jahres als Signal der stärksten Kategorie X. Andere Weltraumwächter wie die Satelliten SOHO und Yohkoh schlugen ebenfalls Alarm.

Auf der Sonnenoberfläche war ein Strahlungsausbruch aufgeflammt. Zugleich schleuderte eine mächtige Eruption aus der höher gelegenen Gashülle der Sonne (der Korona) eine Blase aus elektrisch geladenen Teilchen ins All, die mit 600 Kilometer pro Sekunde davonstoben – Durchschlagskraft genug, um bei Erreichen der Erde schwere Schäden zu verursachen, etwa durch zusammenbrechende Stromnetze.

Die Sonnenforscher gaben jedoch bald Entwarnung: Der Teilchensturm, so zeigten ihre Daten, werde unseren Planeten allenfalls streifen. Tatsächlich wurden nirgendwo Schäden bekannt.

Der Malstrom ionisierter Gase (Physiker sprechen von einem Plasma) war vermutlich nur der Auftakt zu einer ganzen Serie weiterer Weltraumstürme. Denn die Sonne geht dem Maximum ihres Aktivitätszyklus entgegen, das sie Mitte 2000 erreicht. „Bis der nächste heftige koronale Massenauswurf auftritt, ist ▶



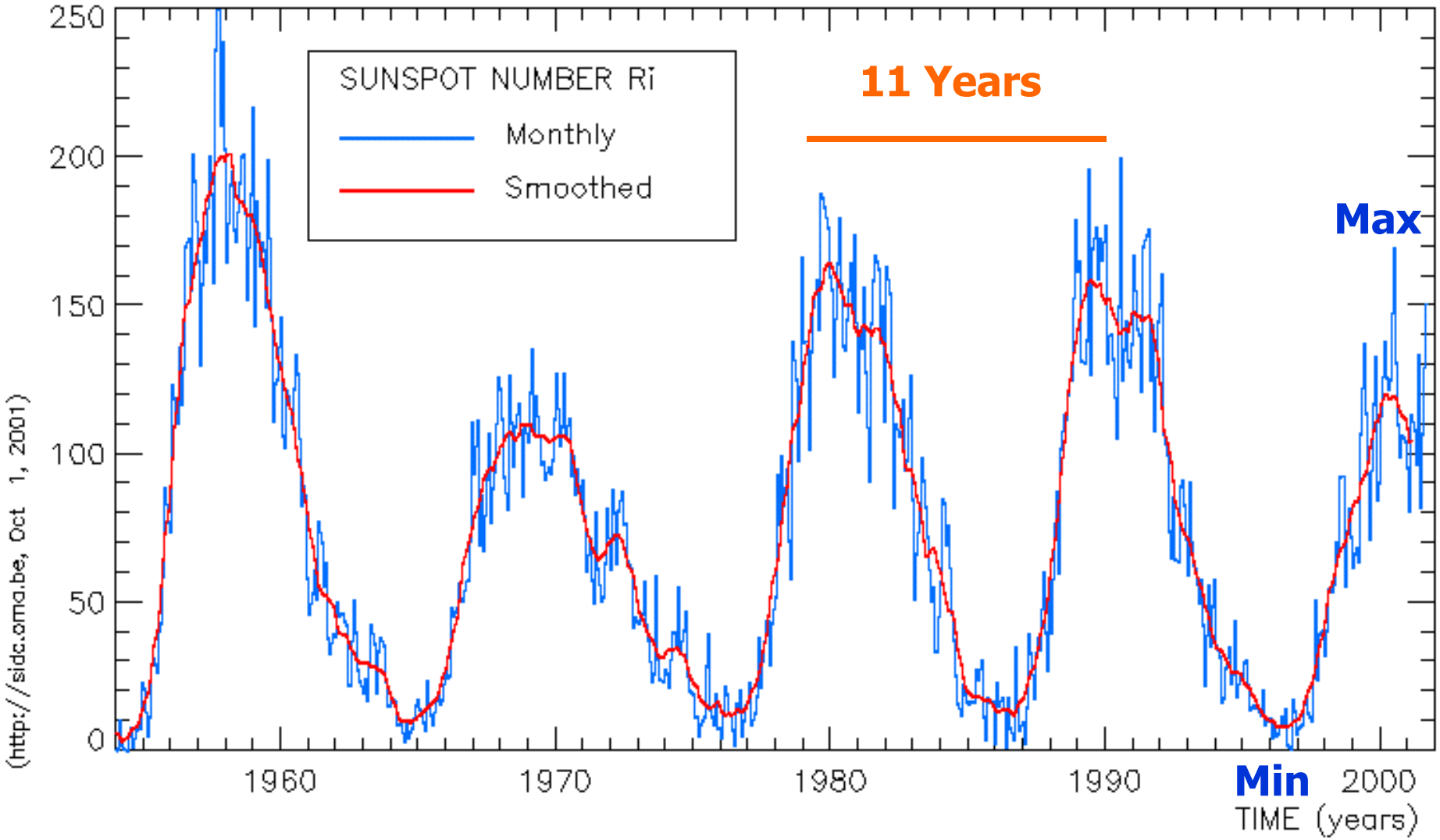
„Die Astronauten der Apollo-Missionen hätten bei ihren Spaziergängen auf dem Mond einen ***solchen Ausbruch*** *vermutlich nicht überlebt"*

VOLKER BOTHMER [SONNENFORSCHER]

Fotos: Yohkoh-Satellit (2), SOHO (3), T. Müller

The Apollo Astronauts would not have survived the Proton Showers in August 1972

The Current Solar Cycle



Key Issues Related to Space Weather

Current status:

tracking of active regions appearing

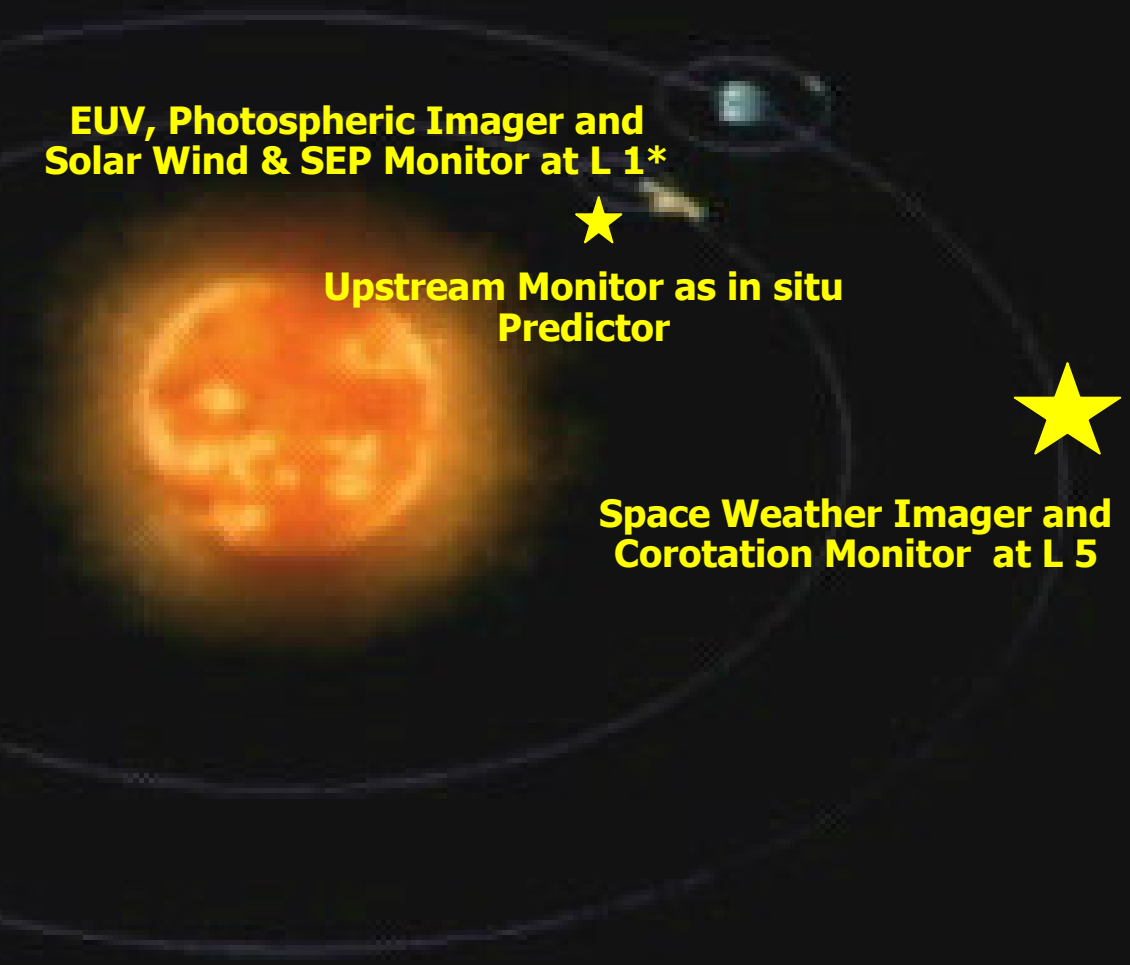
at E-limb

Need: high resolution magnetic field, plasma and coronal observations of the Sun and also improved spectroscopy

A Space Weather Mission Scenario

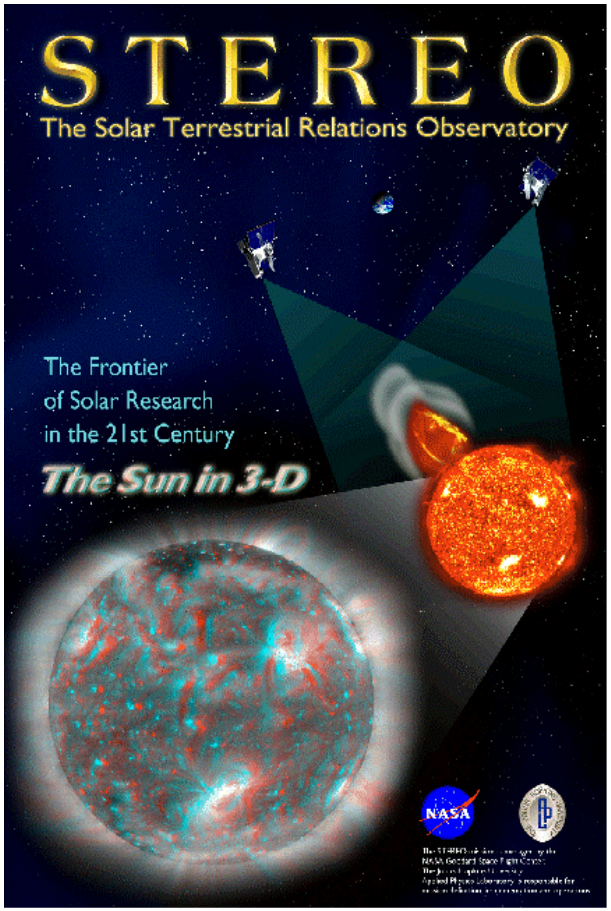
Relevant Instruments

- Coronagraph
- EUV disk imagers
- Magnetograph
- Magnetometer
- Particle Detectors
- Ground Based Magnetograms and H-alpha observations from suitable networks

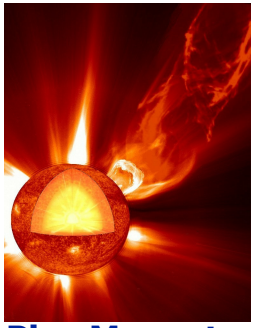


* Prediction time from in situ observations at L1 is at the order of an hour to a few minutes for typical solar wind and CME speeds (450 to more than 2000 km/s).

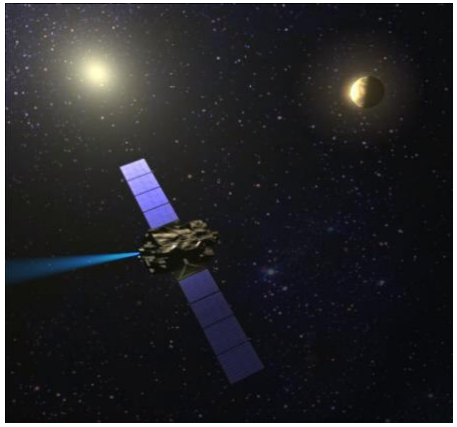
Future ESA/NASA Mission – Leading the Way to a Better Understanding of the Sun-Earth-Connection

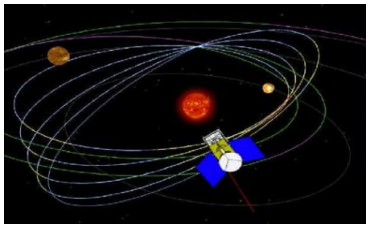


SDO



ESA Solar Orbiter



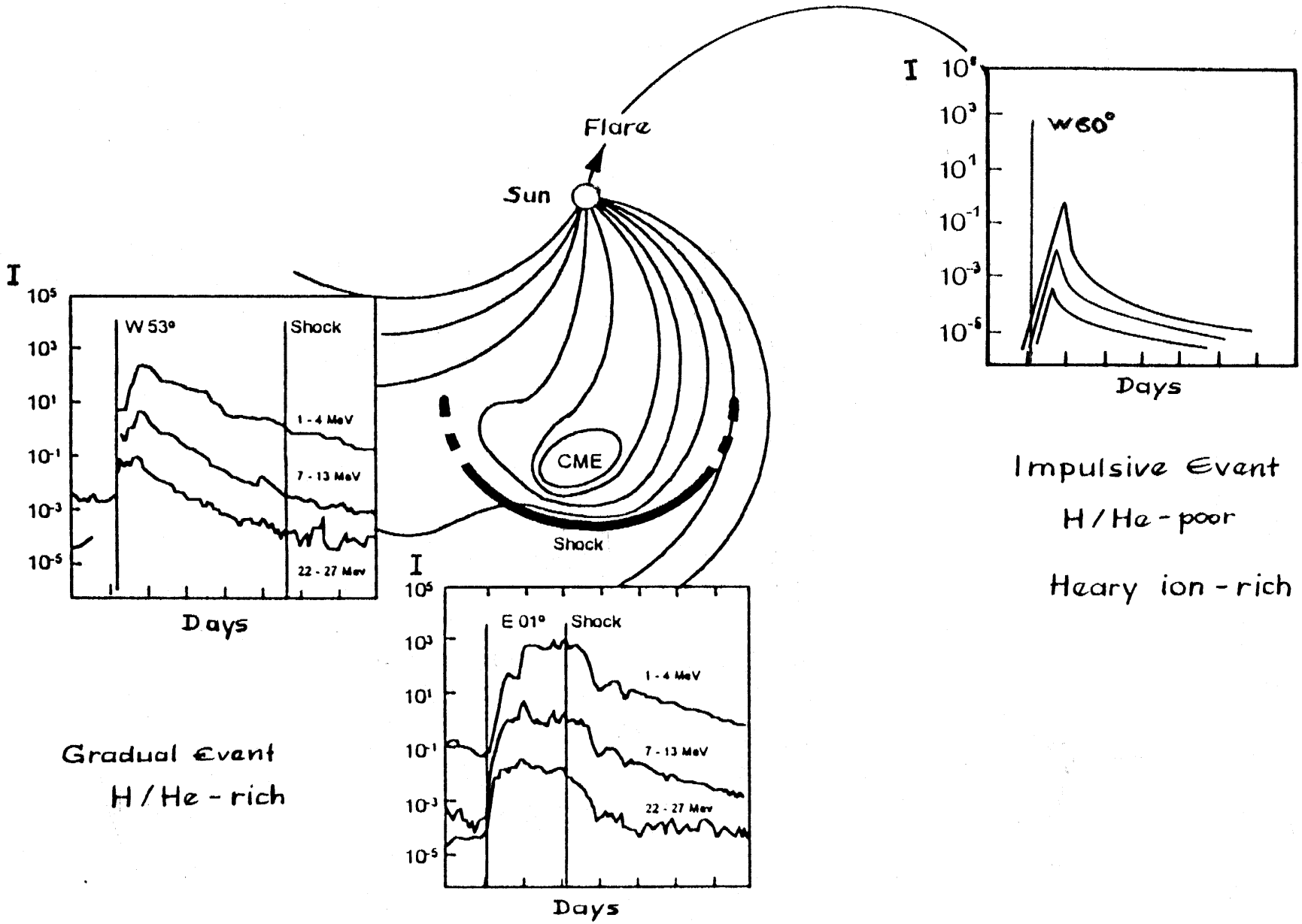


sdo.gsfc.nasa.gov
sci.esa.int/home/solarorbiter

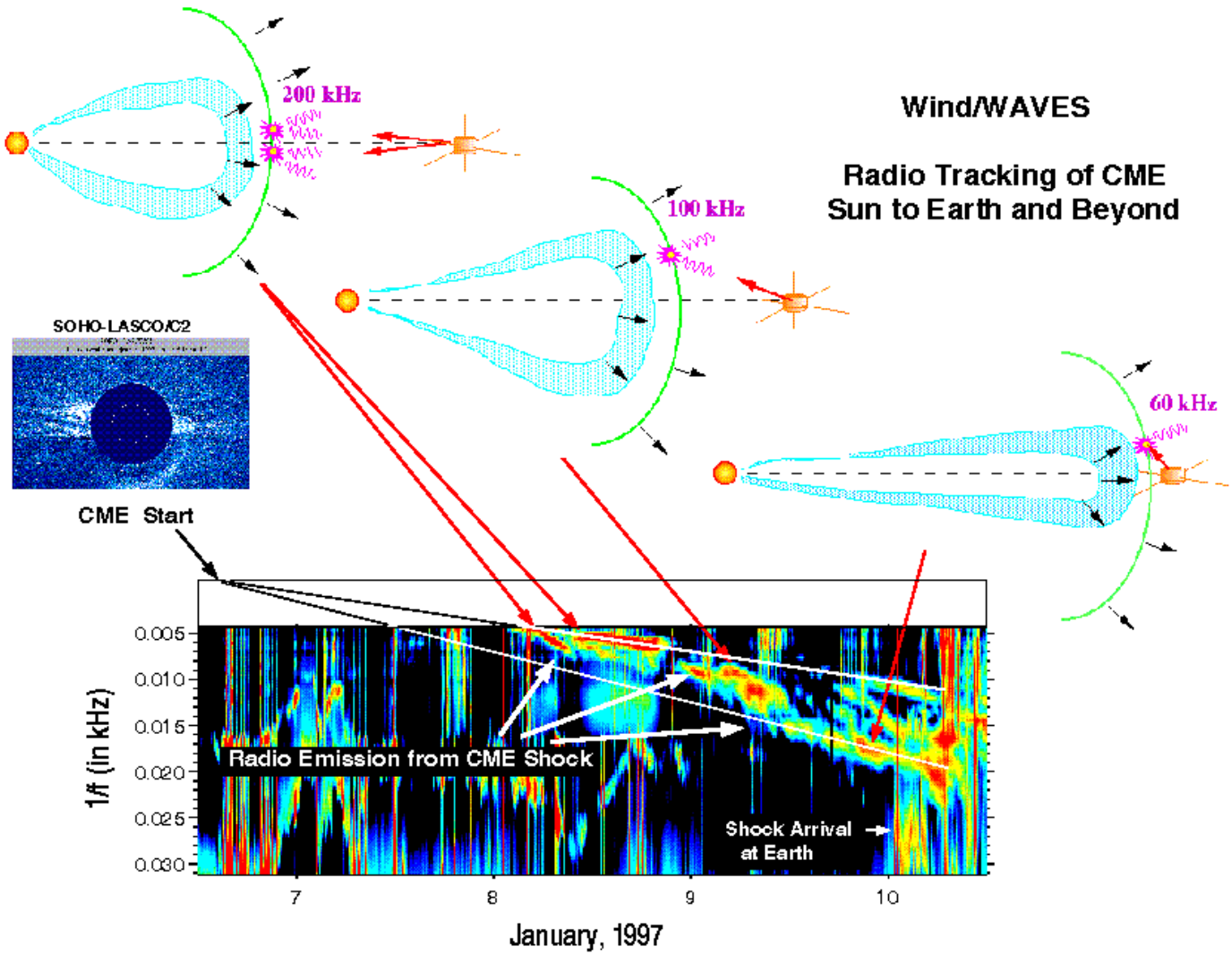
with SOHO, Cluster Hopefully Operational Plus Magnetospheric Missions Like Double Star, Themis, MMS

End of 2005 **2007** **After 2010**

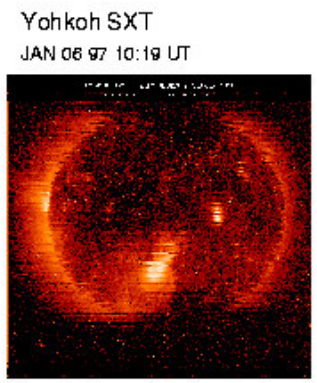
See also NASA's Sun Earth Connection Roadmap at NASA websites

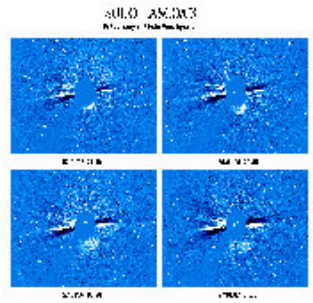

Flare
Sun
CME
Shock
I
W 53°
Shock
1 - 4 MeV
7 - 13 MeV
22 - 27 Mev
Days
Gradual Event
H / He - rich
I
E 01°
Shock
1 - 4 MeV
7 - 13 MeV
22 - 27 Mev
Days
I
W60°
Days
Impulsive Event
H / He - poor
Heary ion - rich

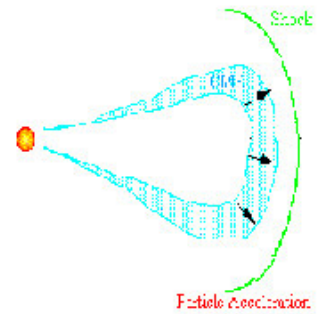
CME tracking through measurements of kilometric radiowaves

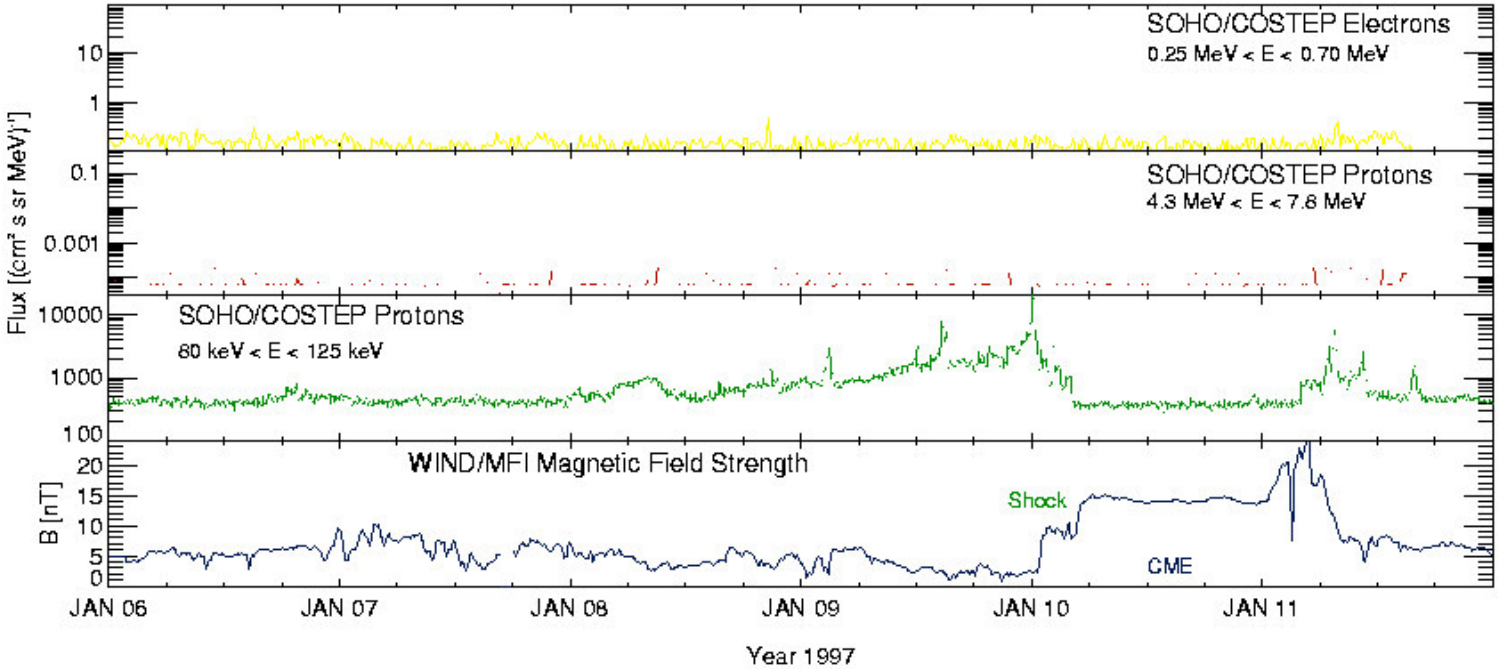


CME Tracking Through Measurements of Energetic Particles

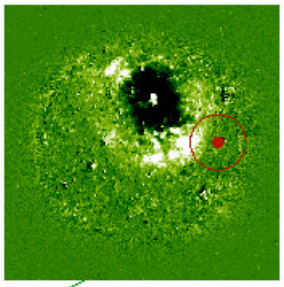


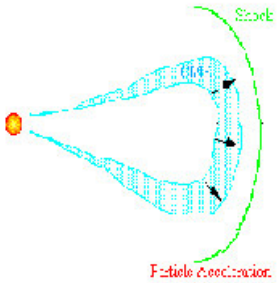


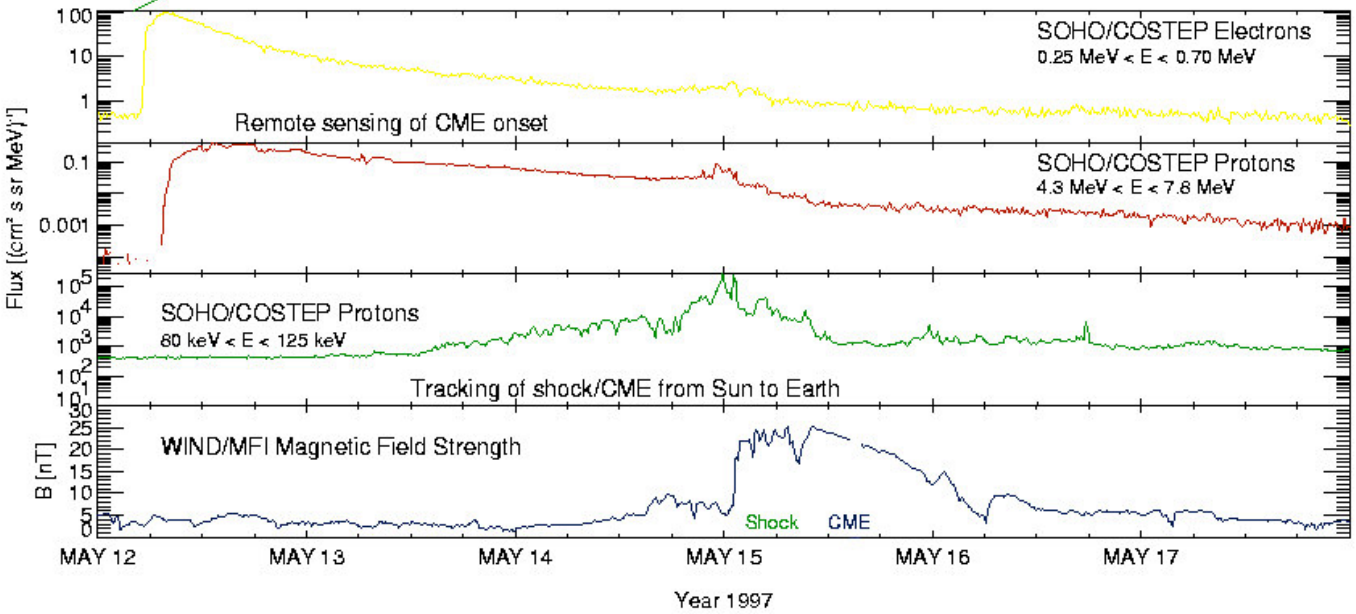


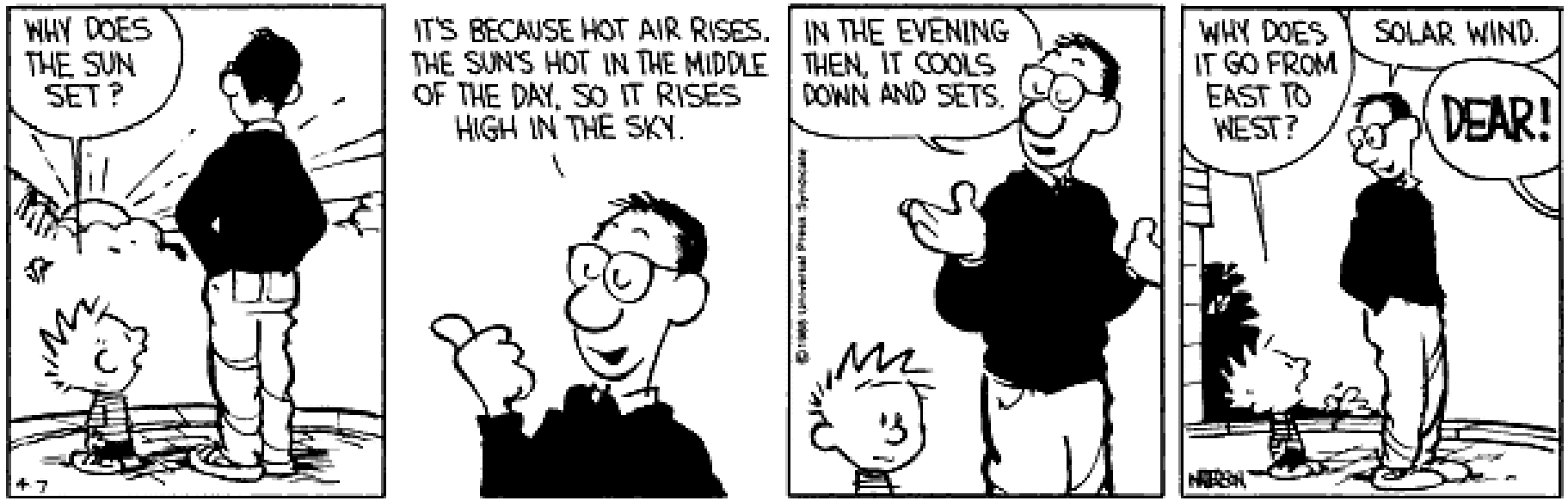


CME Tracking Through Measurements of Energetic Particles








WHY DOES THE SUN SET?
IT'S BECAUSE HOT AIR RISES. THE SUN'S HOT IN THE MIDDLE OF THE DAY, SO IT RISES HIGH IN THE SKY.
IN THE EVENING THEN, IT COOLS DOWN AND SETS.
WHY DOES IT GO FROM EAST TO WEST?
SOLAR WIND.
DEAR!