

Energetic Particles and Storms in Geospace

Ioannis A. Daglis

Department of Physics

National and Kapodistrian University of Athens



Outline

- Geospace and Solar-Terrestrial Coupling
- Energetic particles
- Storms in the Sun-Earth System
- Magnetic storms / magnetospheric substorms
- Van Allen Belts
- Ring Current
- Storm-substorm relationship
- Ring Current and Van Allen Belts coupling



Outline

- **Geospace and Solar-Terrestrial Coupling**
- Energetic particles
- Storms in the Sun-Earth System
- Magnetic storms / magnetospheric substorms
- Van Allen Belts
- Ring Current
- Storm-substorm relationship
- Ring Current and Van Allen Belts coupling



Solar-terrestrial coupling

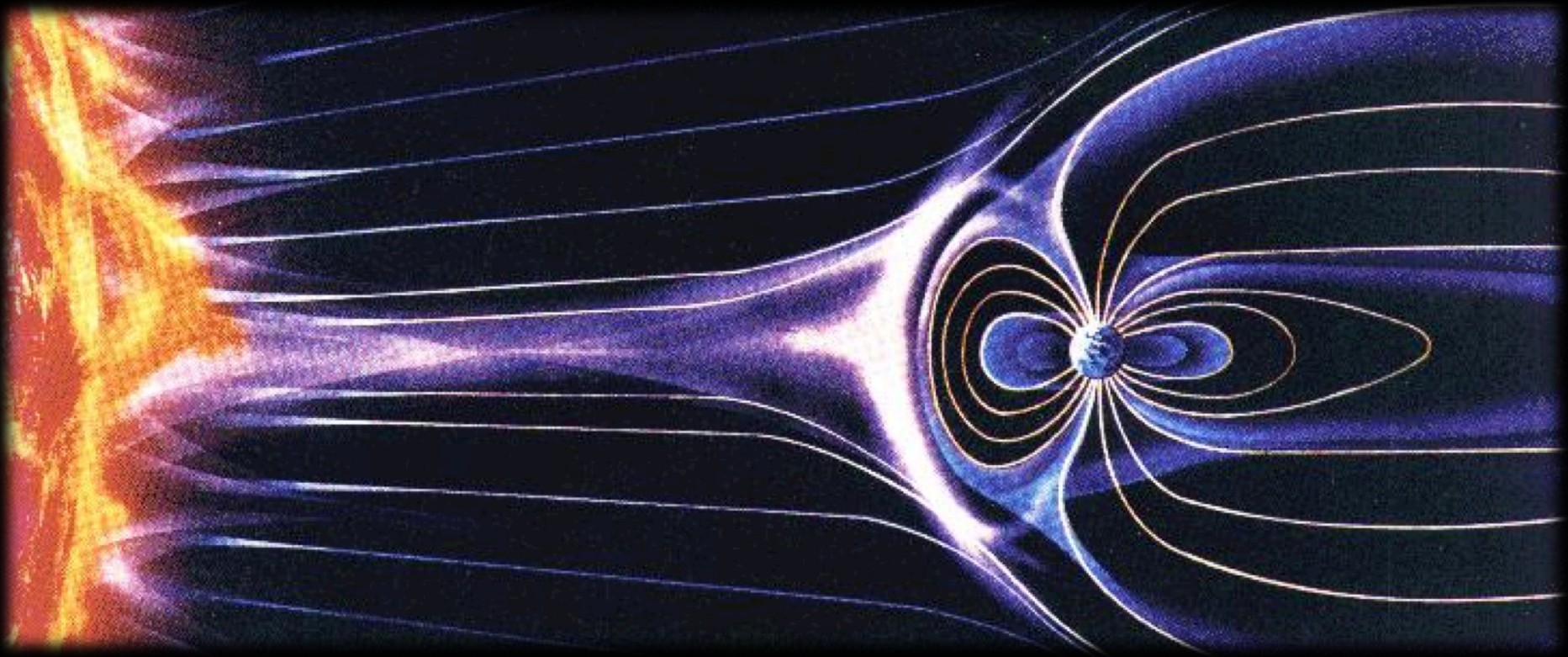
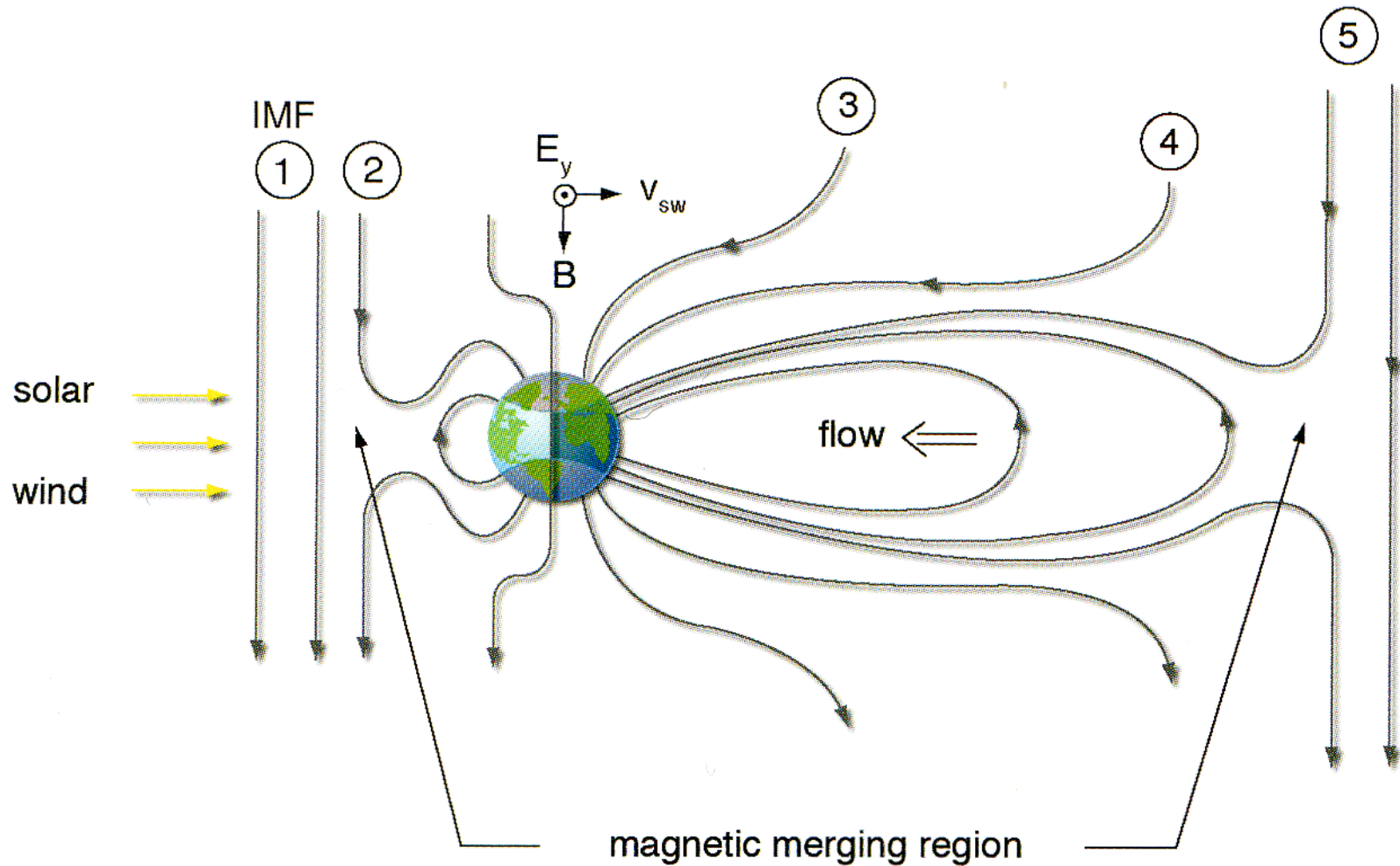
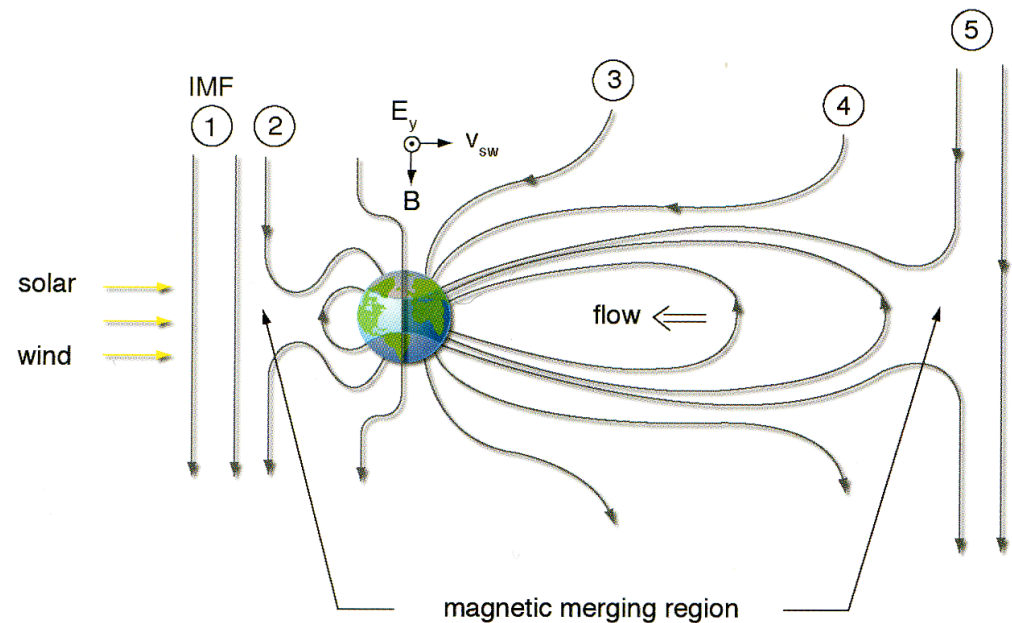
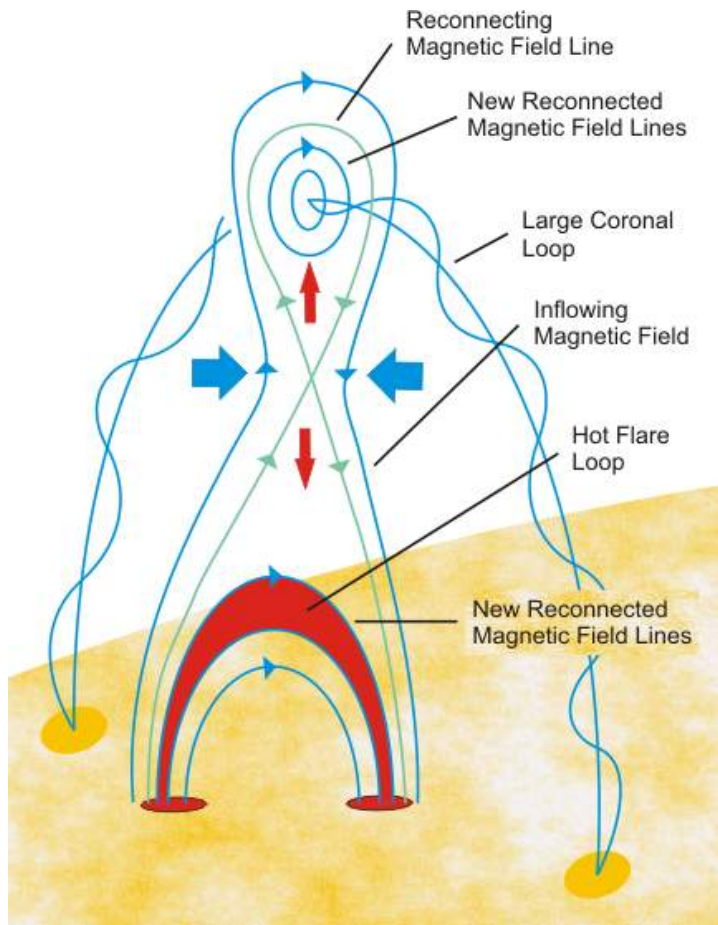


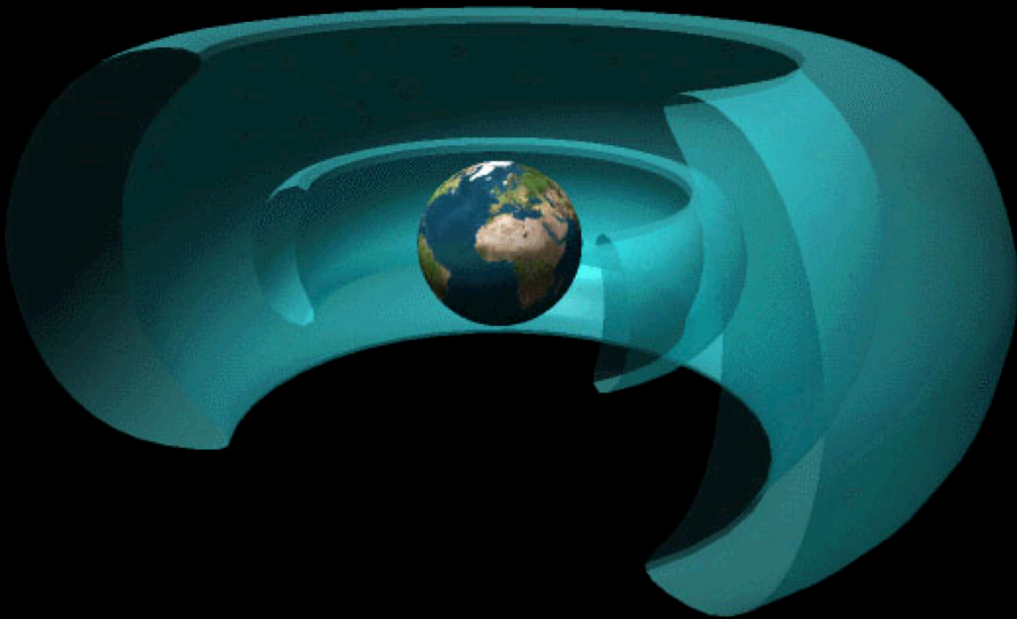
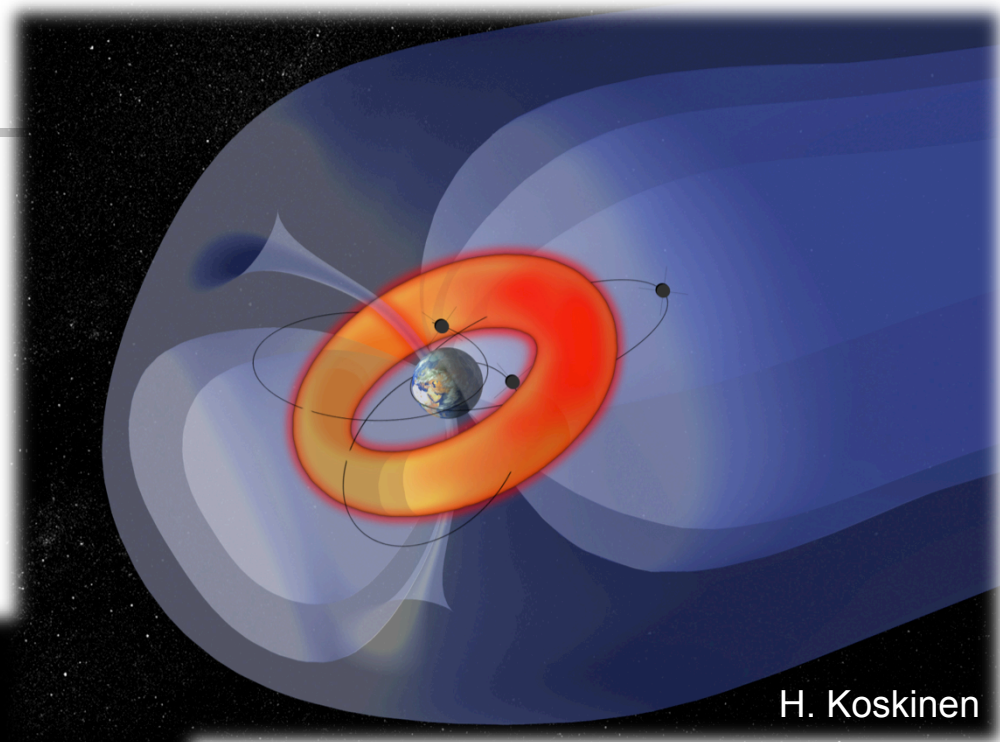
Illustration by K. Endo / Y. Kamide

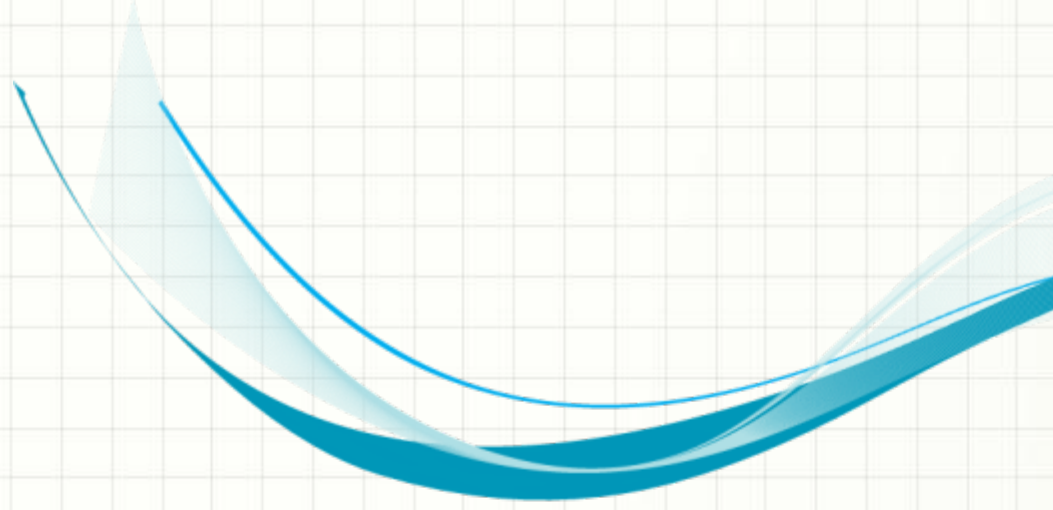
Magnetic reconnection: Transforming magnetic to kinetic energy



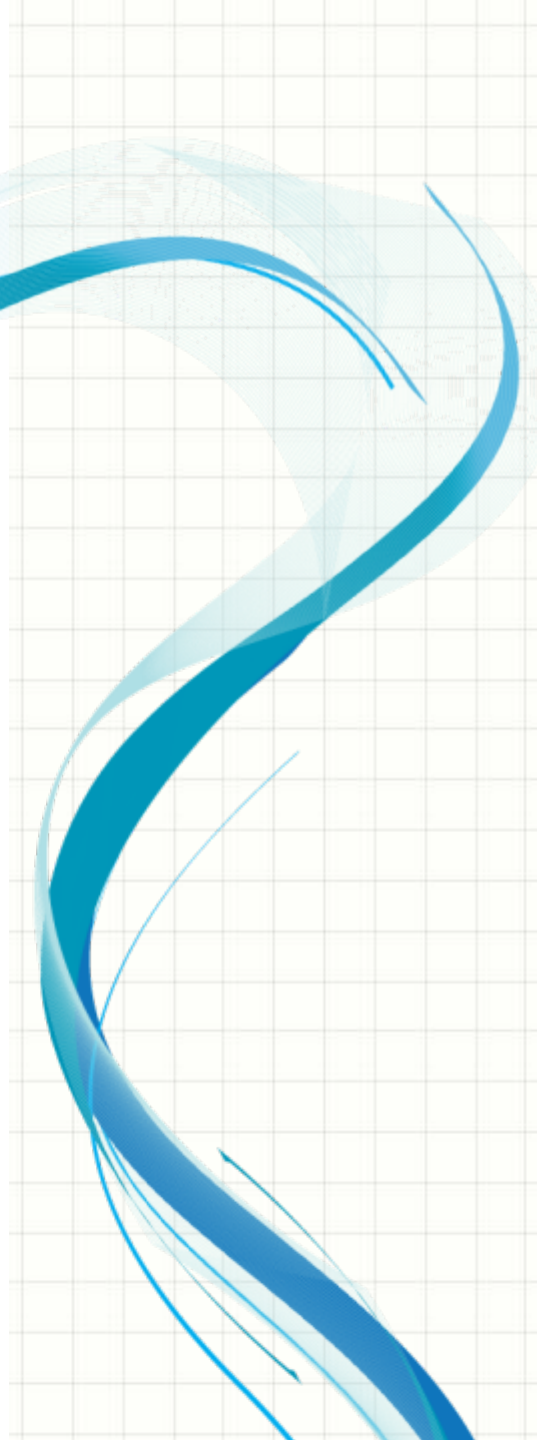
Magnetic reconnection: Transforming magnetic to kinetic energy







NOAA storms classification

A decorative graphic on the left side of the slide, consisting of several overlapping, flowing blue lines that curve upwards and then downwards, creating a sense of movement and energy.

Radio blackouts
Solar radiation storms
Geospace magnetic storms
(or Geomagnetic storms)



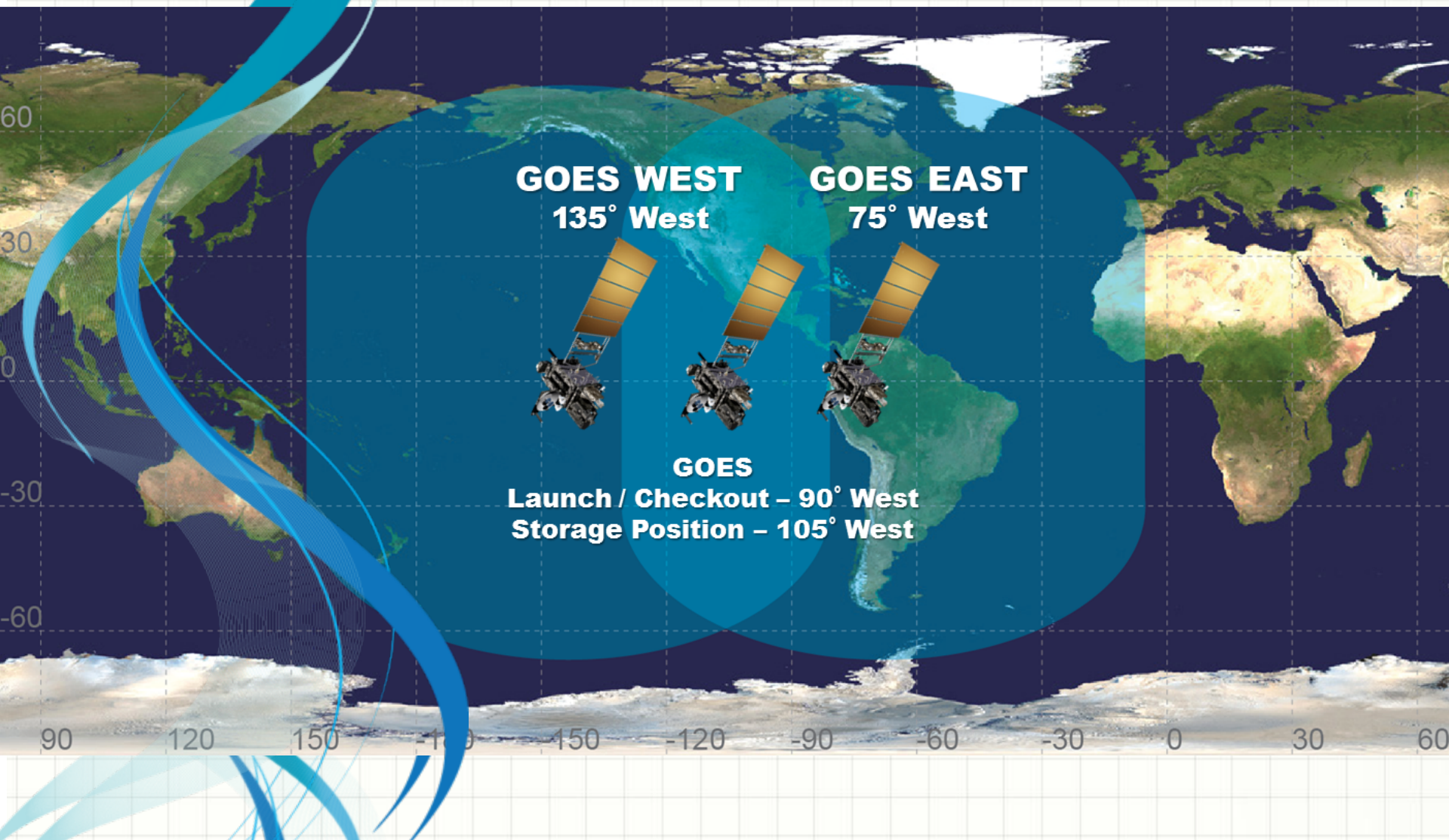
Radio blackouts:

X-rays from solar flares -
critical for SatCom and SatNav
Minor - Moderate - Strong -
Severe - Extreme

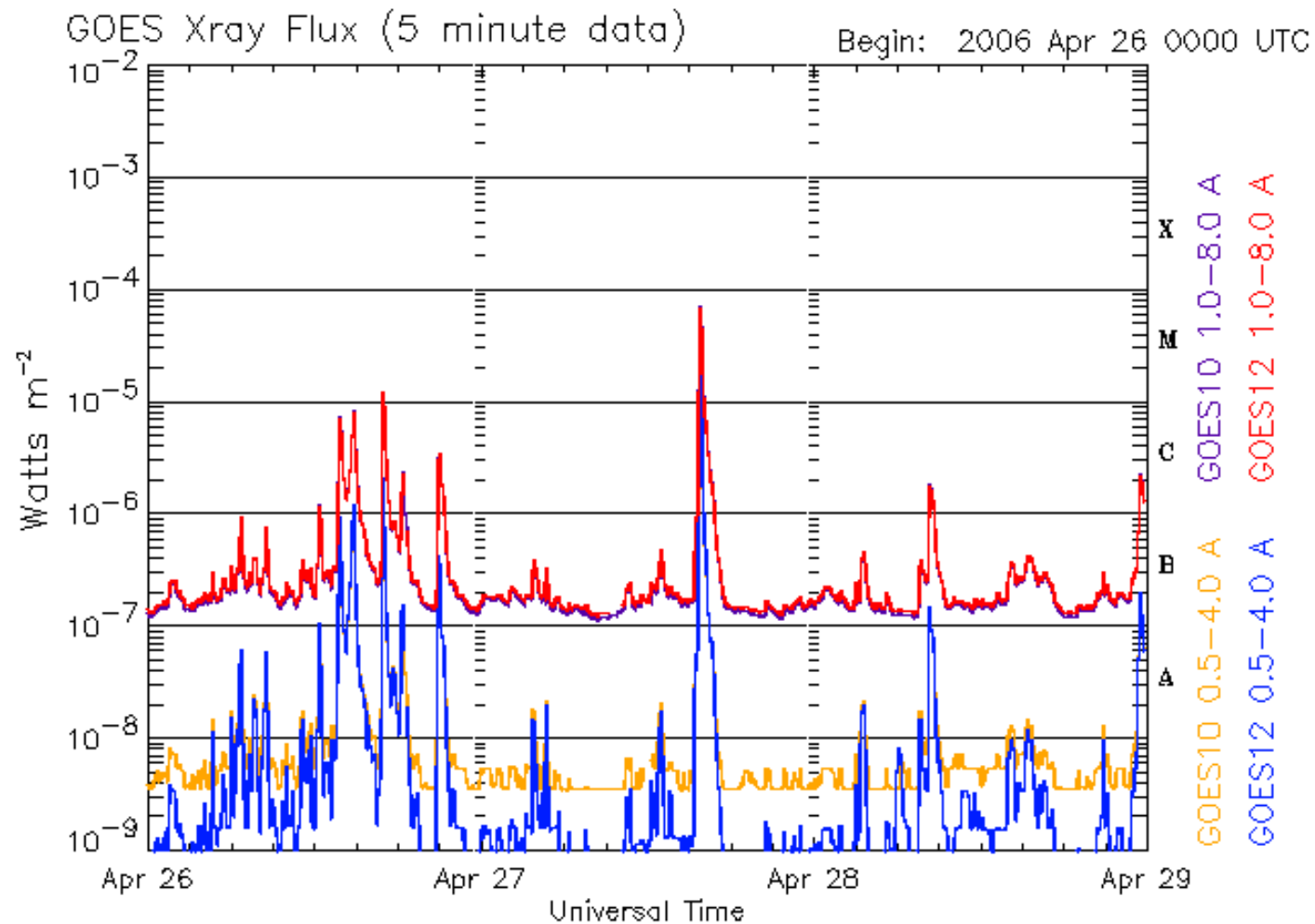
GOES X-ray monitor:

M1 - M5 - X1 - X10 - X20

GOES



Soft X-Ray Light Curves from GOES (Geostationary Operational Environmental Satellites)

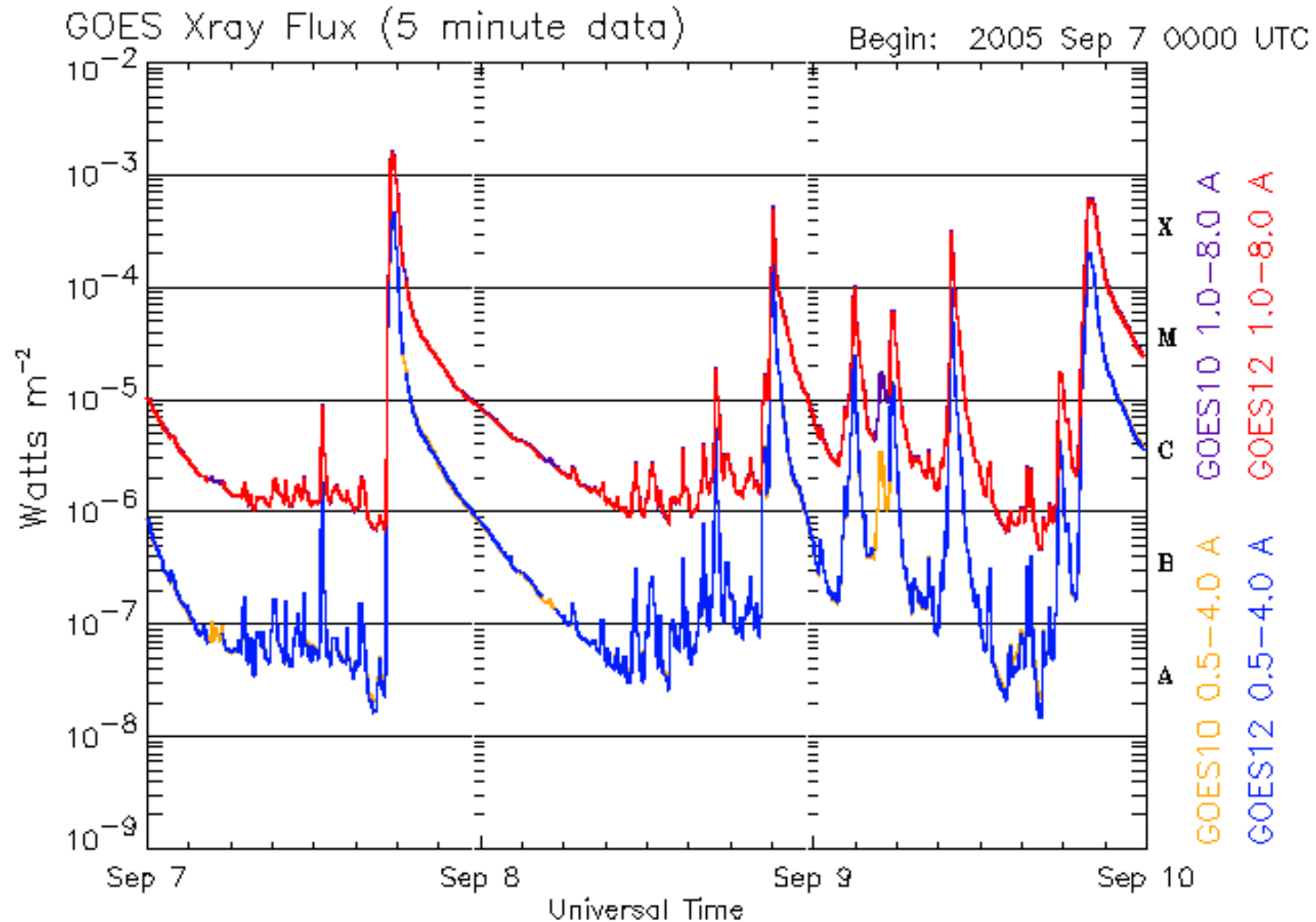


Updated 2006 Apr 28 23:56:05 UTC

NOAA/SEC Boulder, CO USA

M7 Flare

Soft X-Ray Light Curves from GOES (Geostationary Operational Environmental Satellites)



Updated 2005 Sep 9 23:56:04 UTC

NOAA/SEC Boulder, CO USA

X17 Flare



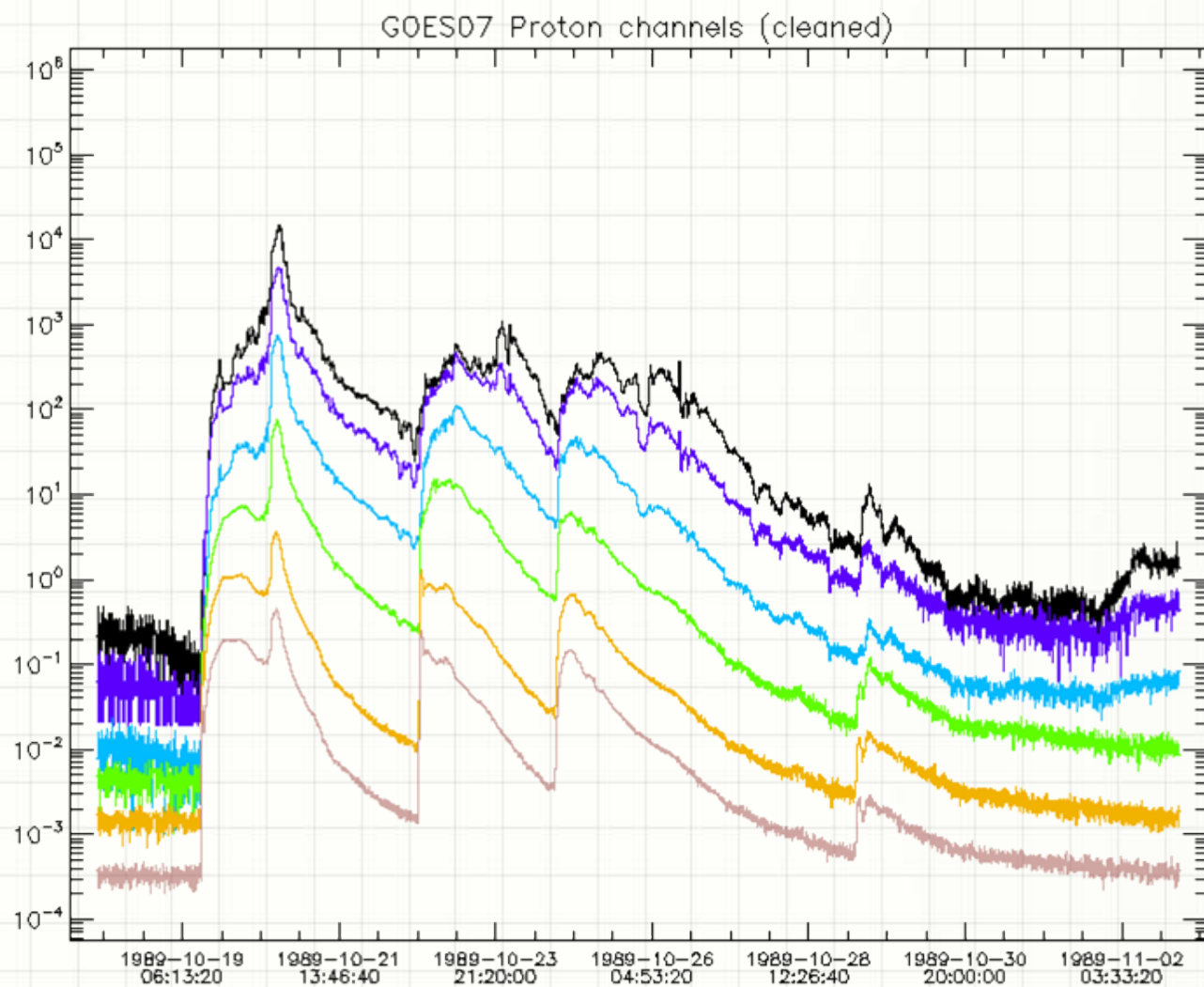
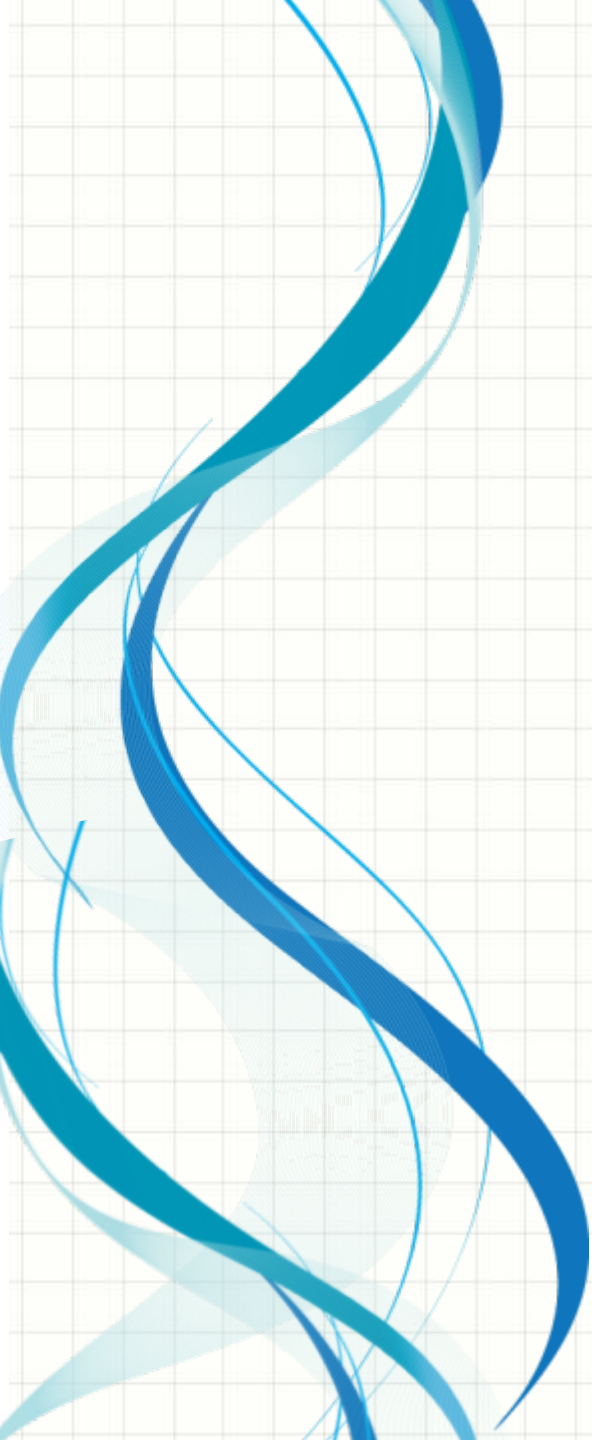
Solar radiation storms:

SEPs - impacts on spacecraft
and humans

Minor - Moderate - Strong-
Severe - Extreme

Flux of energetic ions >10 MeV

$10 - 10^2 - 10^3 - 10^4 - 10^5$





Geomagnetic storms:

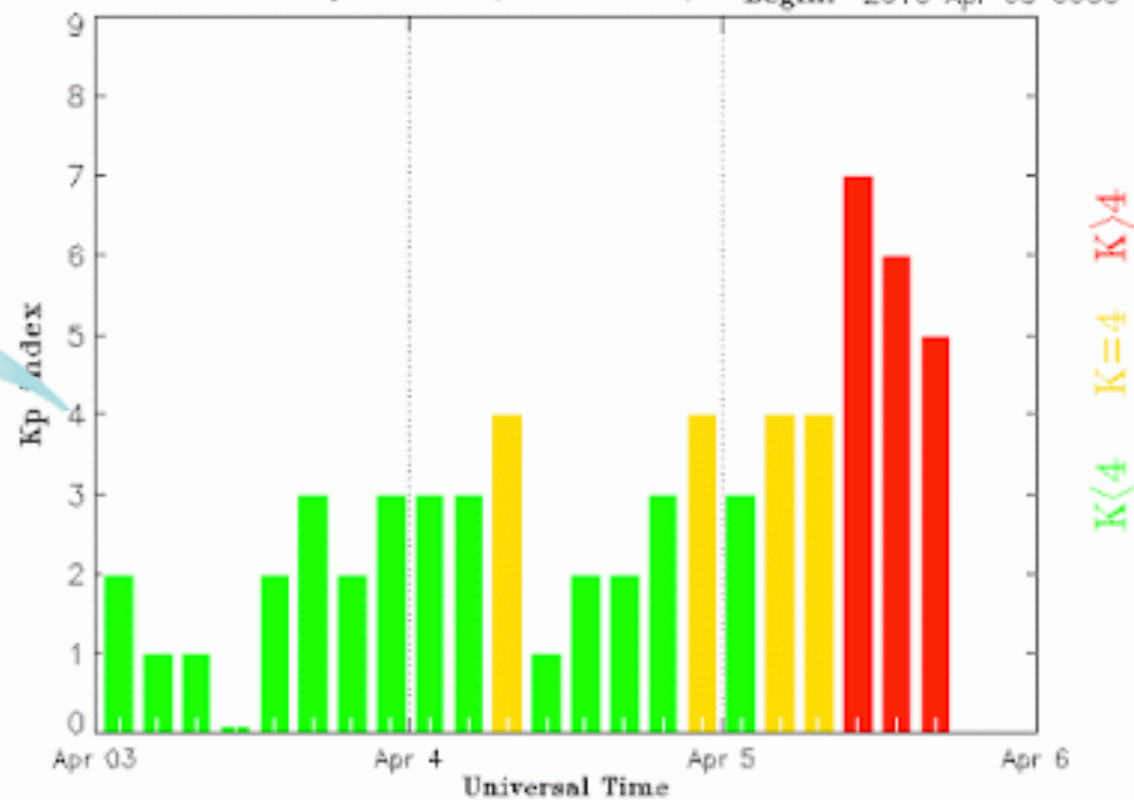
Global magnetic disturbances
in geospace

Minor - Moderate - Strong-
Severe - Extreme

Kp: 5, 6, 7, 8, 9

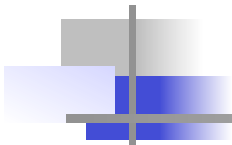
Estimated Planetary K index (3 hour data)

Begin: 2010 Apr 03 0000 UTC

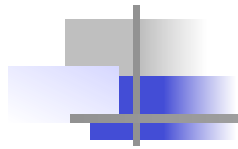


Updated 2010 Apr 5 20:55:02 UTC

NOAA/SWPC Boulder, CO USA



Magnetospheric substorms



Magnetospheric substorms
formerly aka
Auroral substorms



Single most defining feature:

Auroral displays

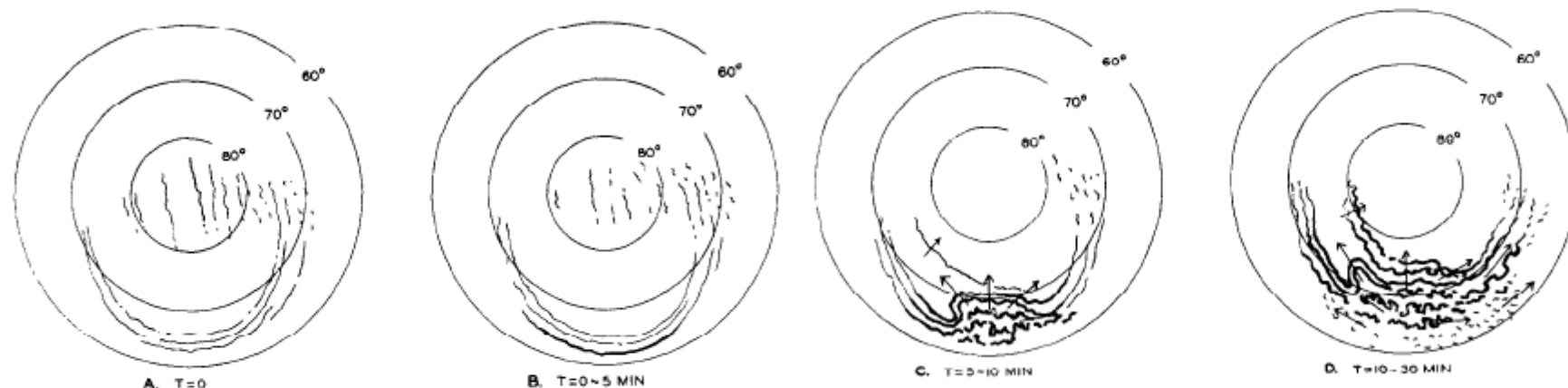
THE DEVELOPMENT OF THE AURORAL SUBSTORM

S.-I. AKASOFU

Geophysical Institute, University of Alaska, College, Alaska

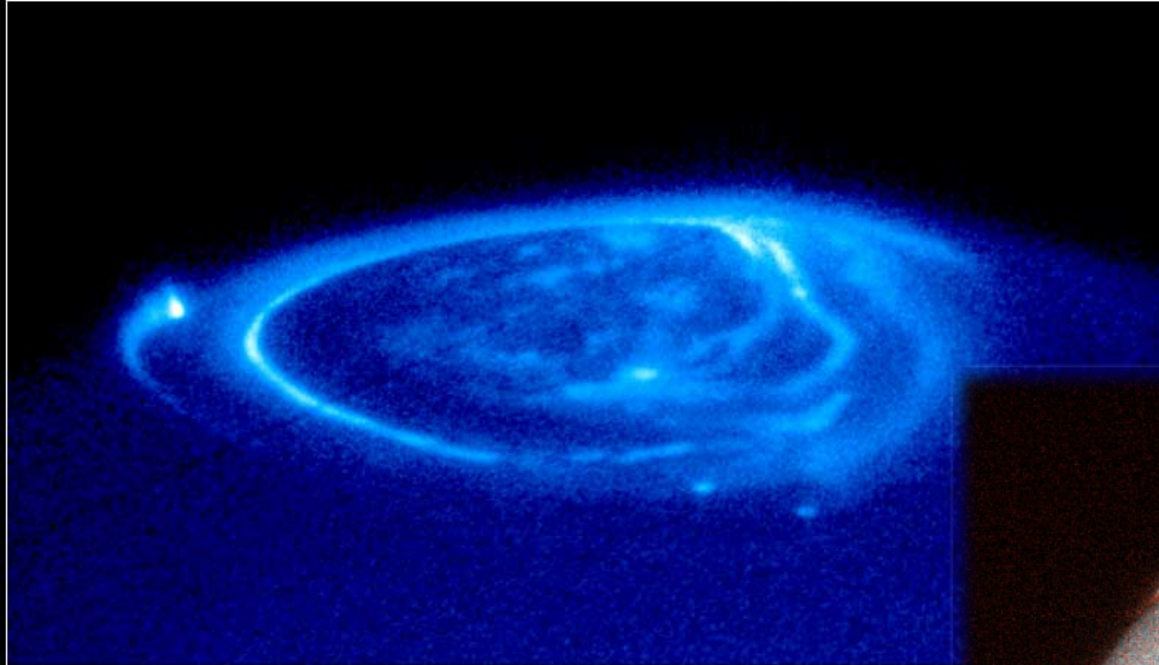
(Received 13 January 1964)

Abstract—A working model of simultaneous auroral activity over the entire polar region is presented in terms of the auroral substorm. The substorm has two characteristic phases, an expansive phase and a recovery phase. Each phase is divided into three stages, and characteristic auroral displays over the entire polar region during each stage are described in detail. Further, all the major features seen at a single station are combined into a consistent picture of large-scale auroral activity.



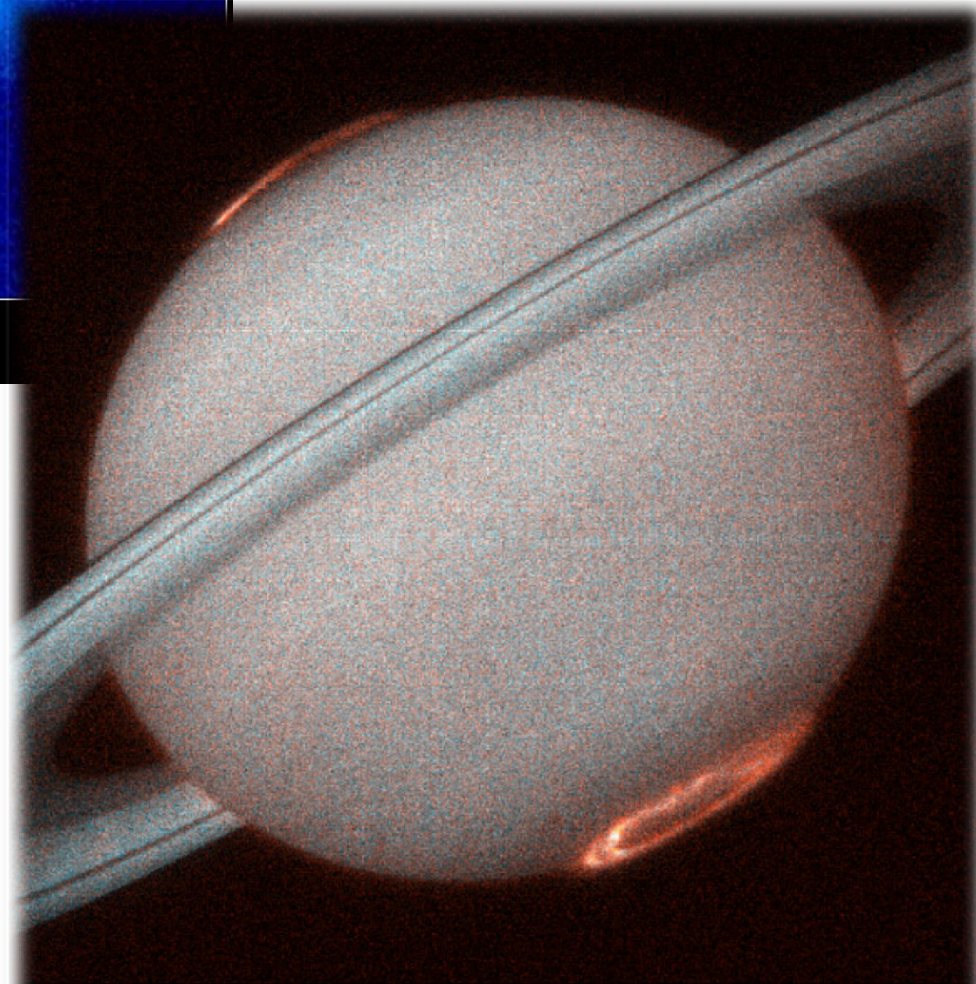


The Aurora



Jupiter Aurora

NASA and J. Clarke (University of Michigan) • STScI-PRC00-38

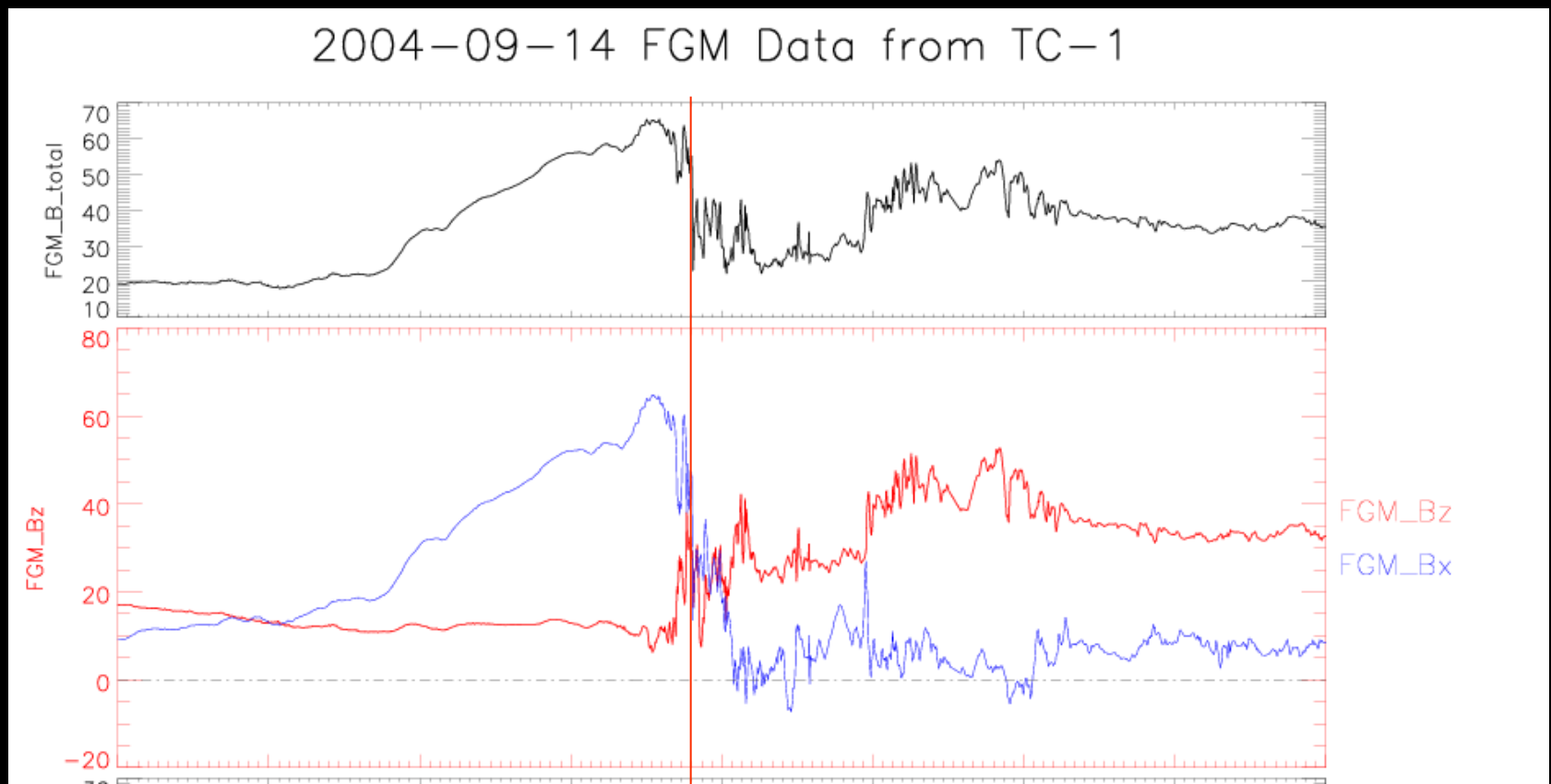


Saturn Aurora

HST • STIS
PRC98-05 • ST ScI OPO • January 7, 1998 • J. Trauger (JPL) and NASA

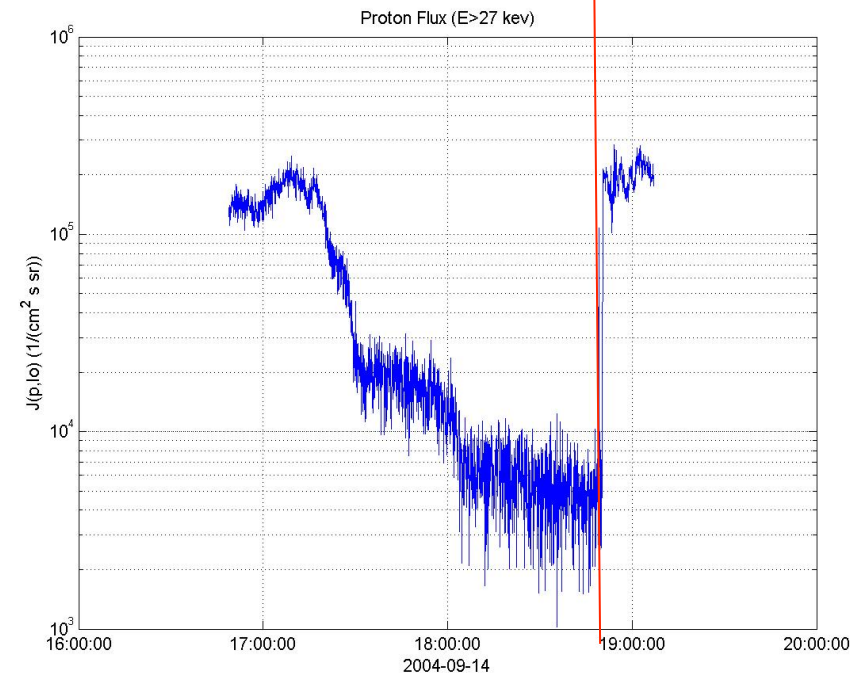
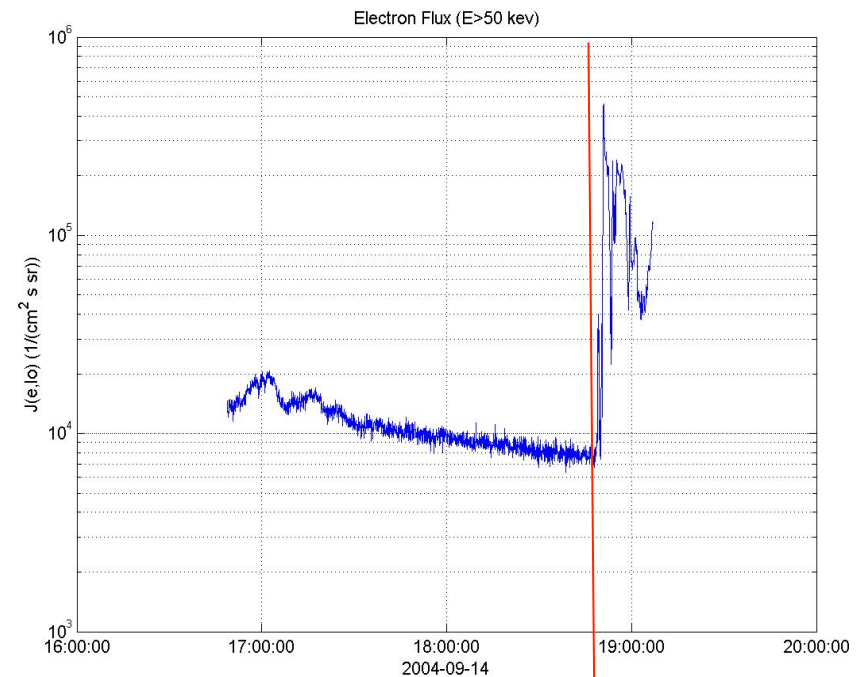
Typical substorm features

Magnetic field reconfigurations
(stretching followed by dipolarization)



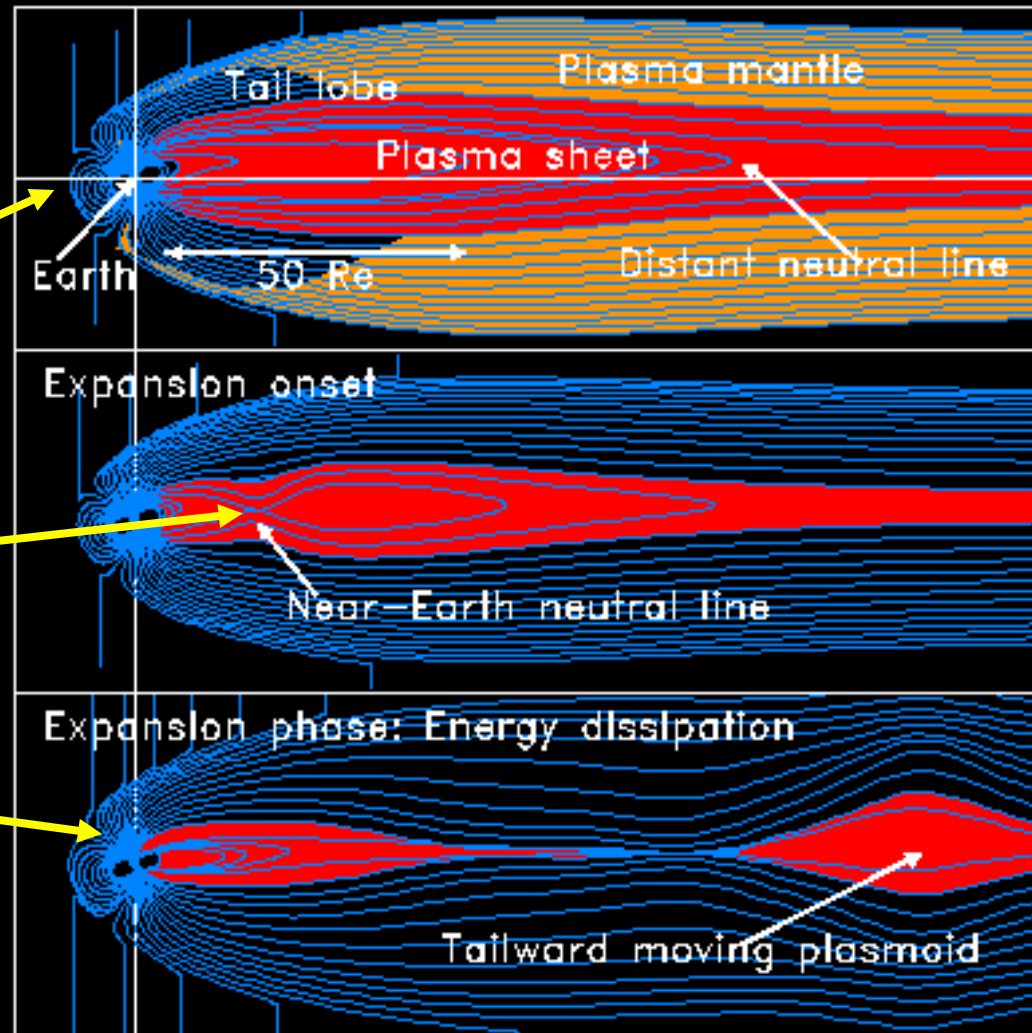
Typical substorm

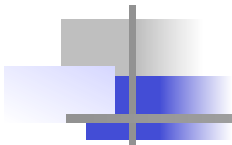
Particle acceleration
and injection into
inner magnetosphere



Magnetospheric substorms

- Duration: 1-3 hours
- Energy: 10^{15} - 10^{16} J
- dayside reconnection = energy loading
- nightside reconnection = msph. reconfigurations, energy dissipation, particle acceleration, plasmoid ejection
- auroral brightening, field-aligned currents, Joule heating
- Rate: several / day

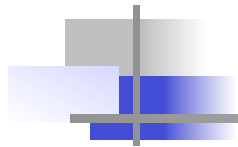




Geospace magnetic storms



Geospace magnetic storms
aka
Geomagnetic storms



Geospace magnetic storms
aka
Geomagnetic storms
aka
Magnetic storms

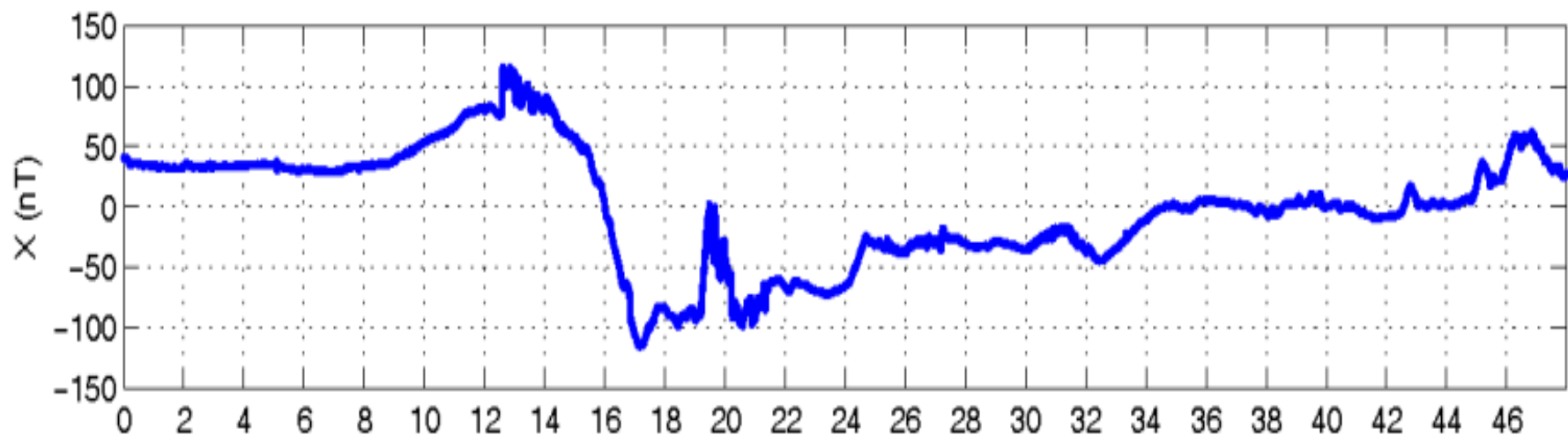
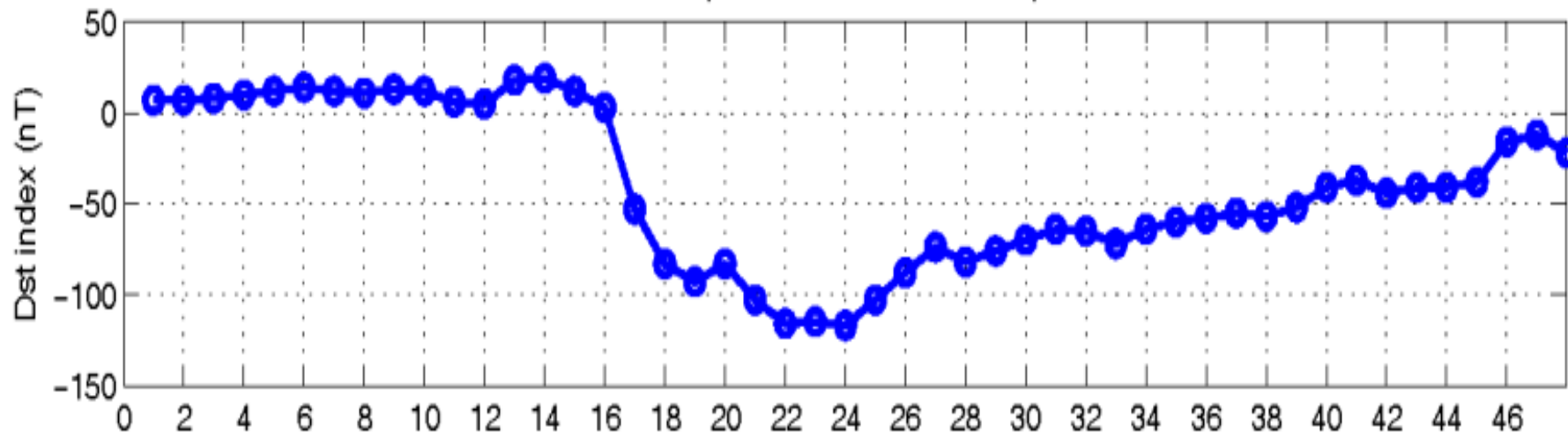


Single most defining feature:

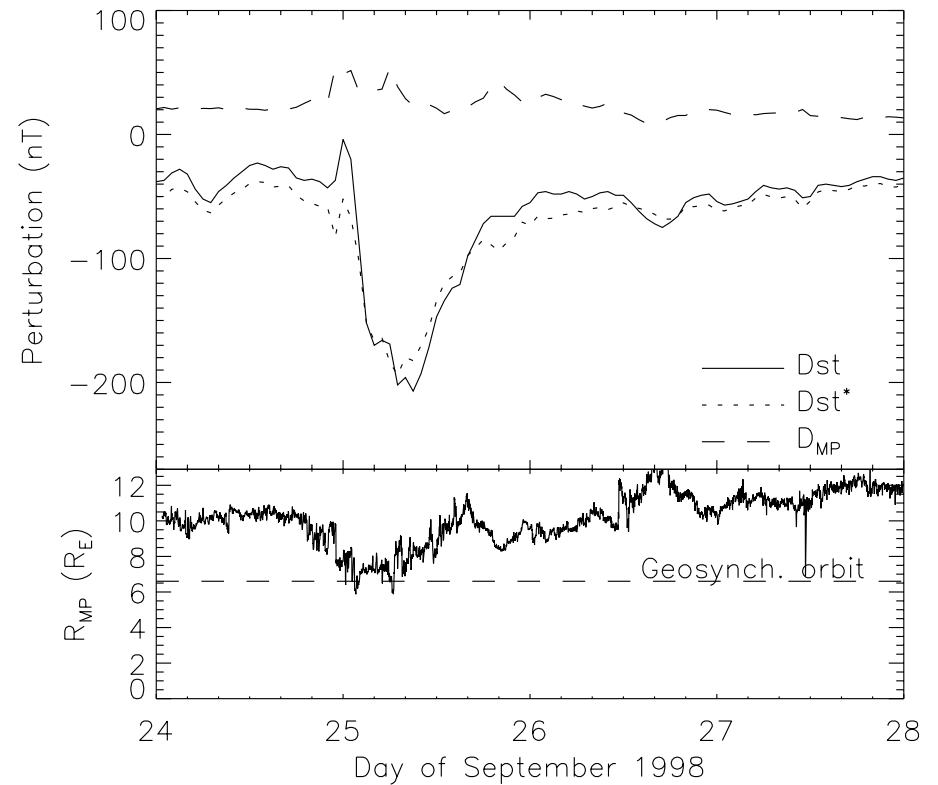
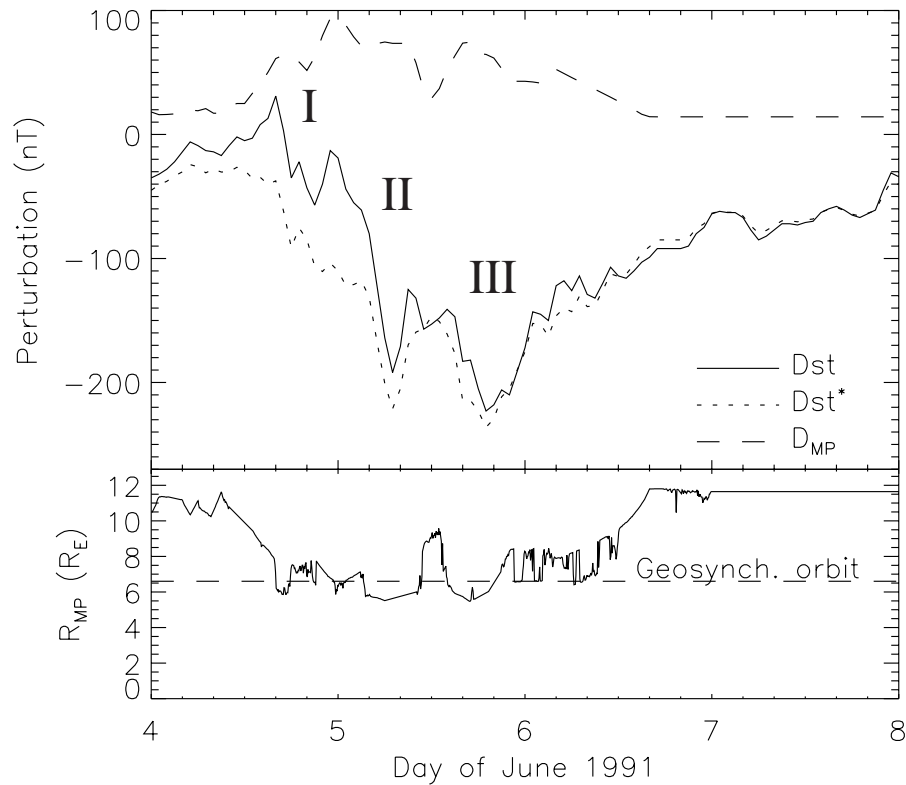
Global Geomagnetic Field Depression

Geospace Magnetic Storms

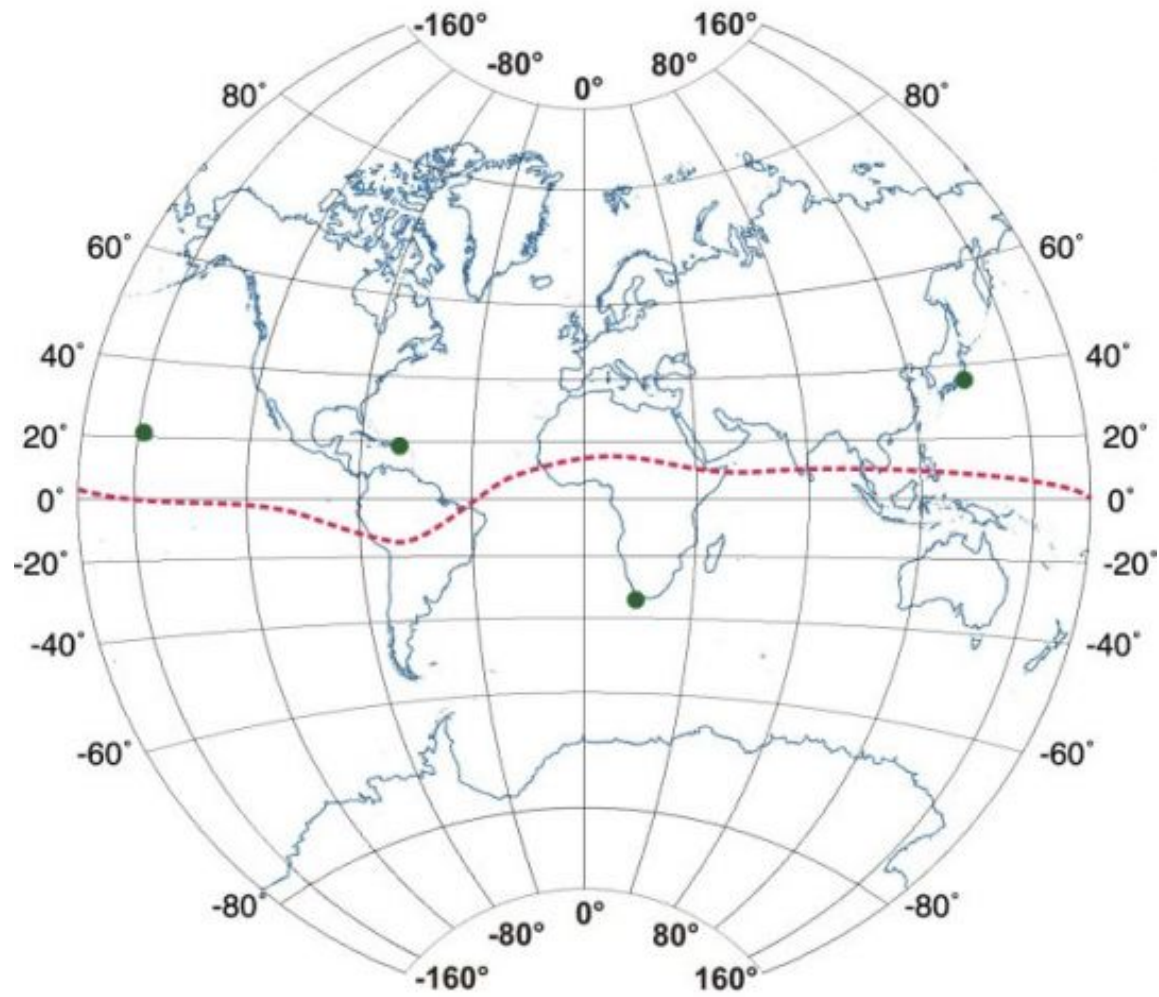
VELIES, from 26-Sep-2011 00:00:00 to 27-Sep-2011 23:59:59

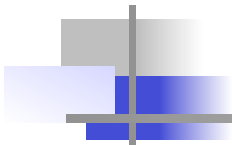


Geospace Magnetic Storms



Daglis et al., PSS2007





Single most defining feature:

Global Geomagnetic Field Depression

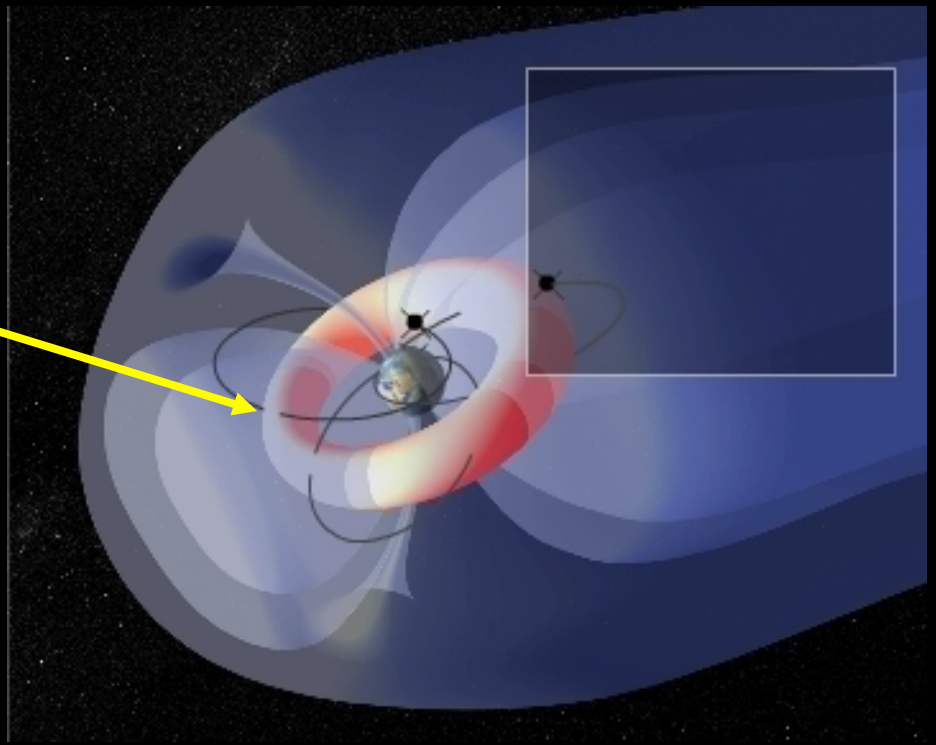
which can be explained

through the diamagnetic effect

of a giant (ring) current flowing around the Earth

Geospace magnetic storms

- Duration: 1-3 days
- Energy: $10^{16} - 10^{17}$ J
- Magnetosphere:
 - ◆ global B disturbances
 - ◆ intense currents (RC)
 - ◆ particle acceleration
- Auroral regions
 - ◆ bright auroral displays
 - ◆ intense ionospheric currents (electrojets)
 - ◆ rapid surface B variations
- Rate: 1/month





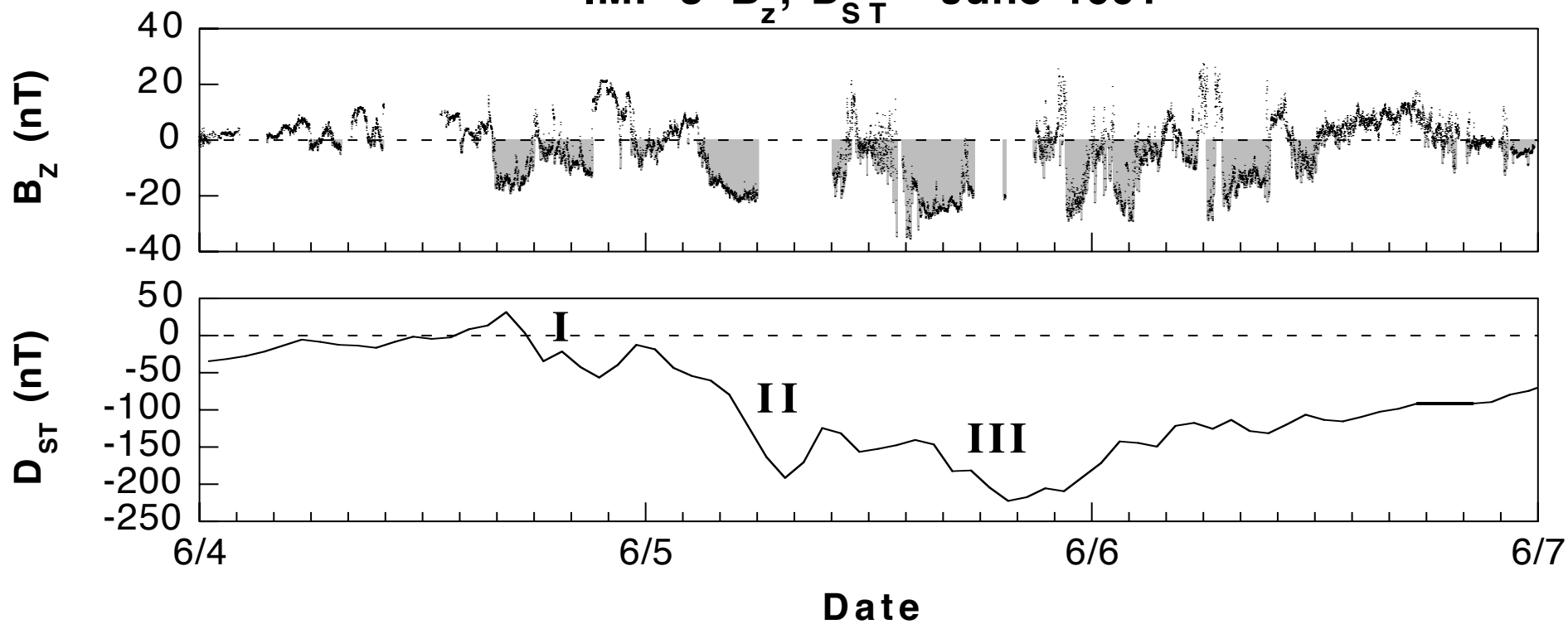
Main storm driver

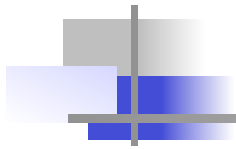
Strong and prolonged (many hours)

southward directed IMF

as seen in some ICMEs

IMP-8 B_z , D_{ST} - June 1991





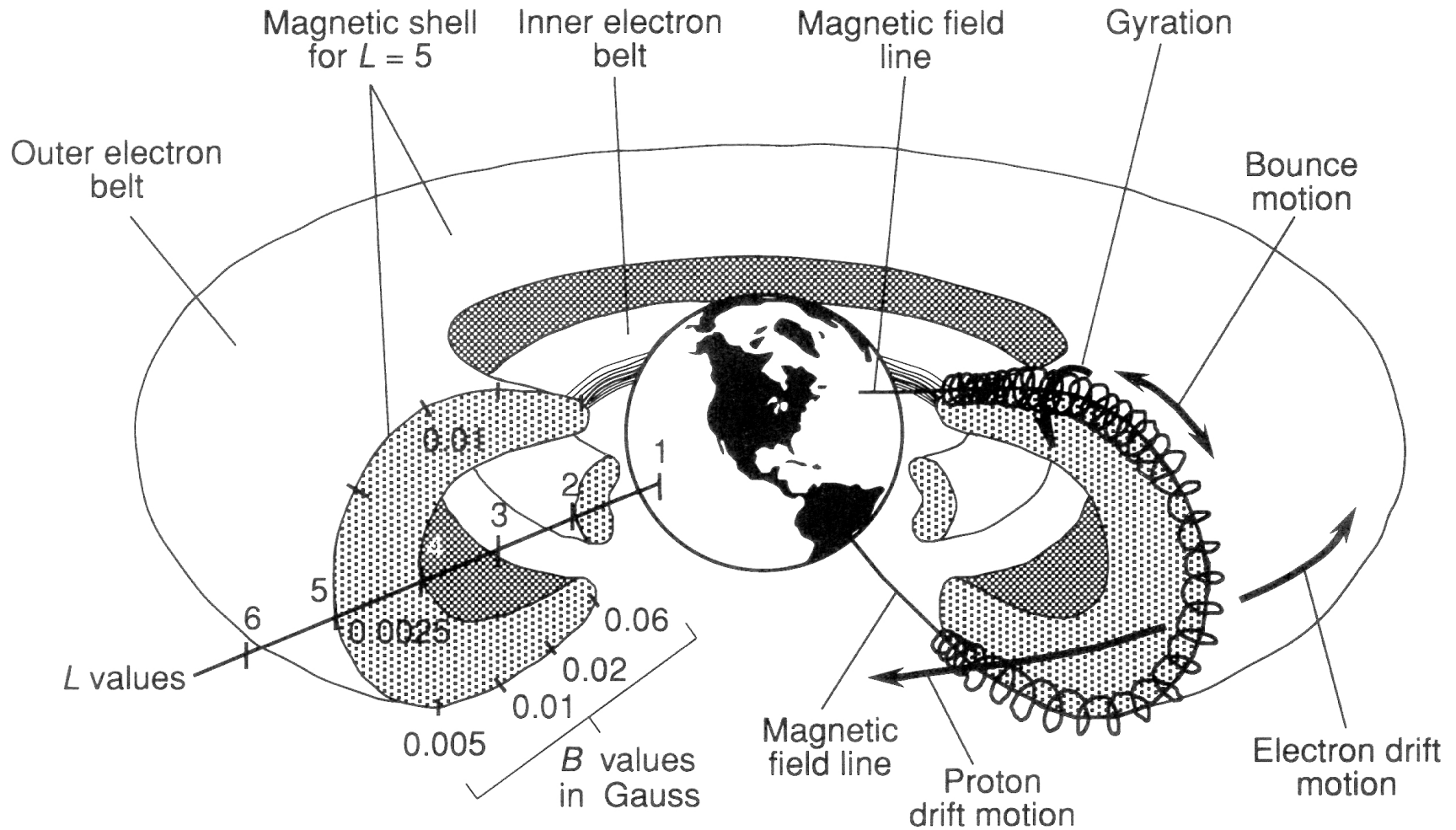
Van Allen Belts



Van Allen Belts
aka
Radiation Belts

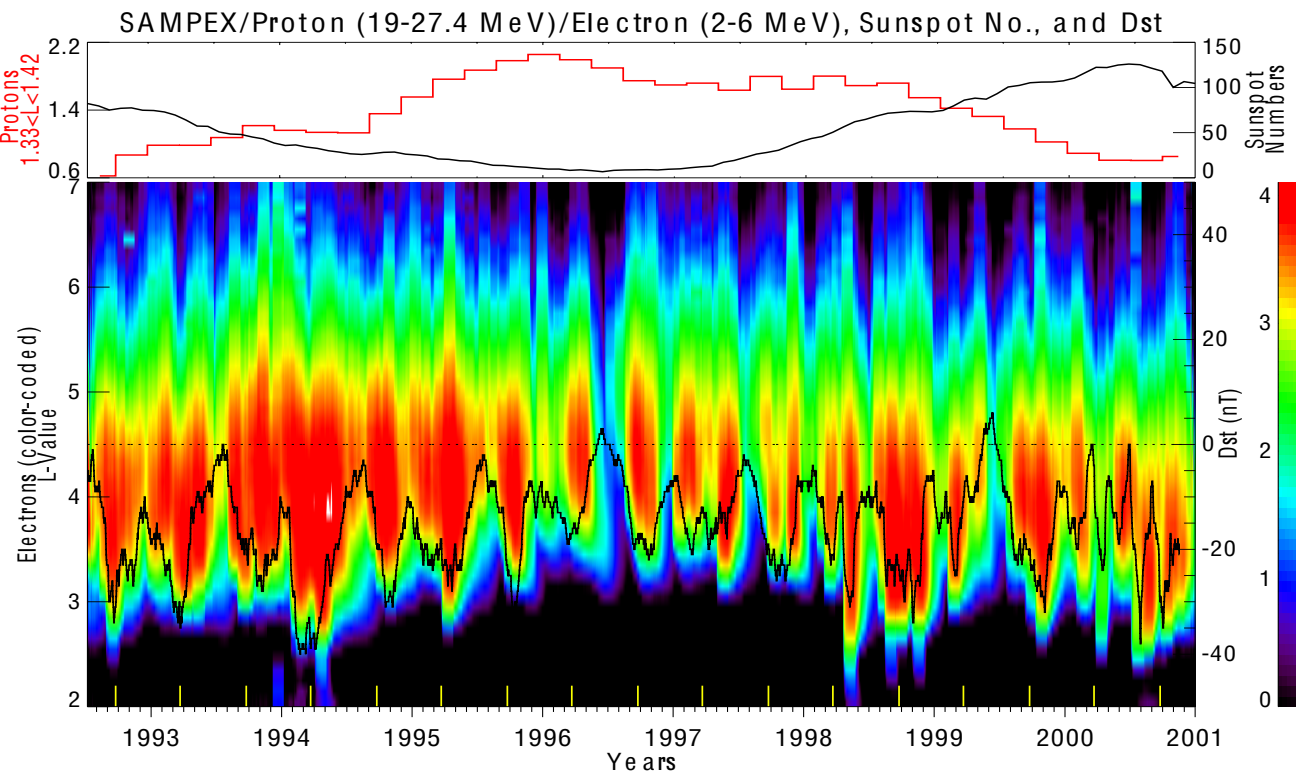


Radiation belts



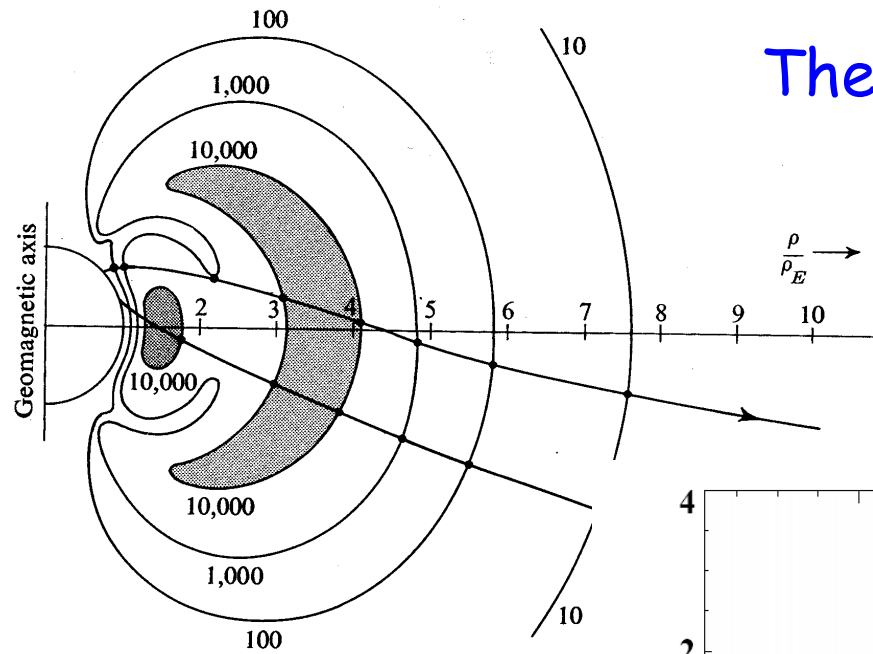
Flux variability in the radiation belts

The radiation belts exhibit substantial variation in time:

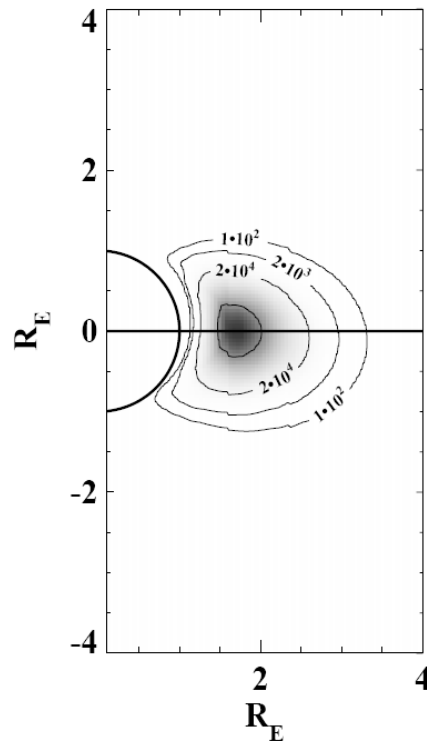


- Solar cycle: years
- Season: Months
- Solar rotation: 13-27 days
- Storm recovery: days
- Storm main phase: hours
- SSC: minutes

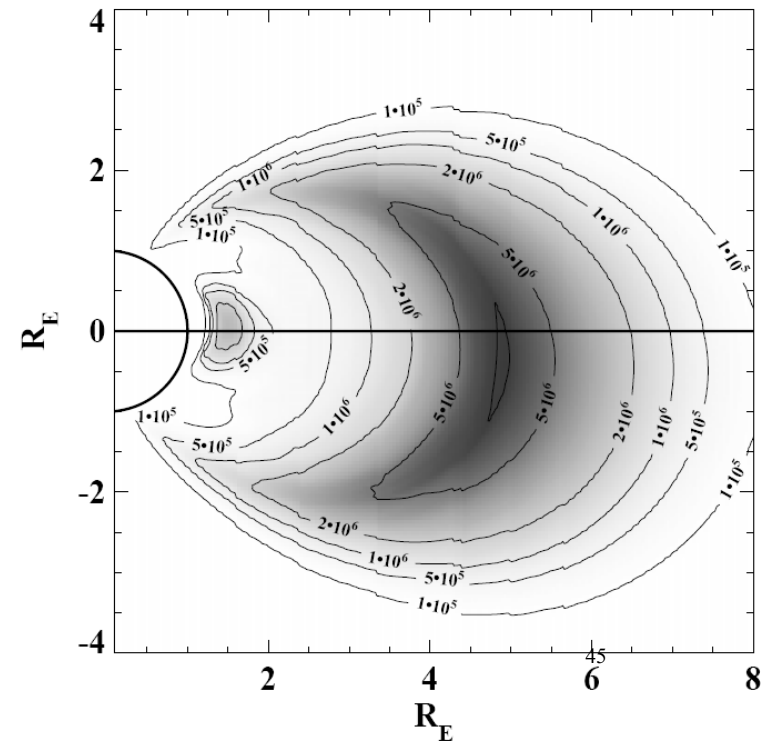
Radiation belts



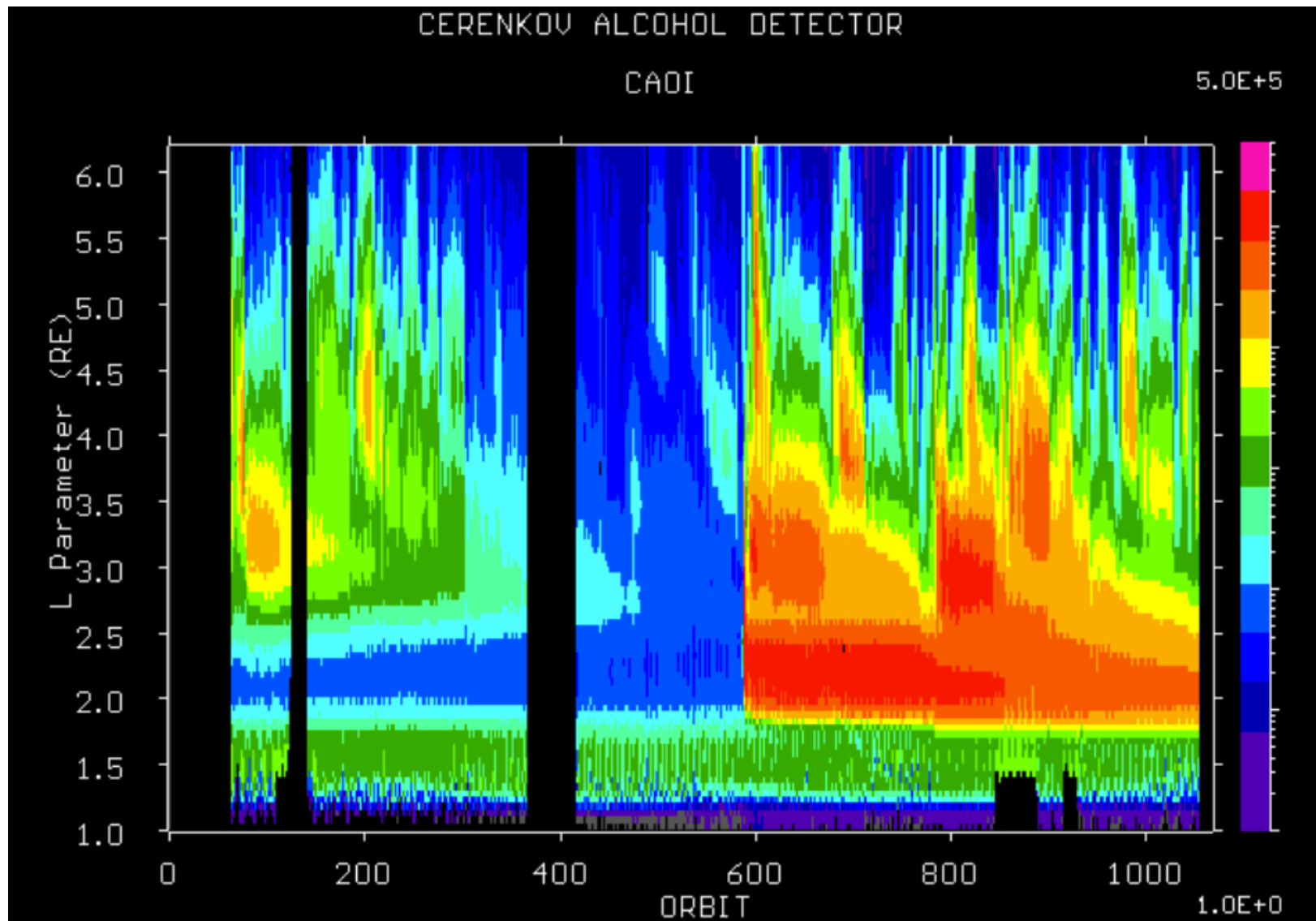
Then ...



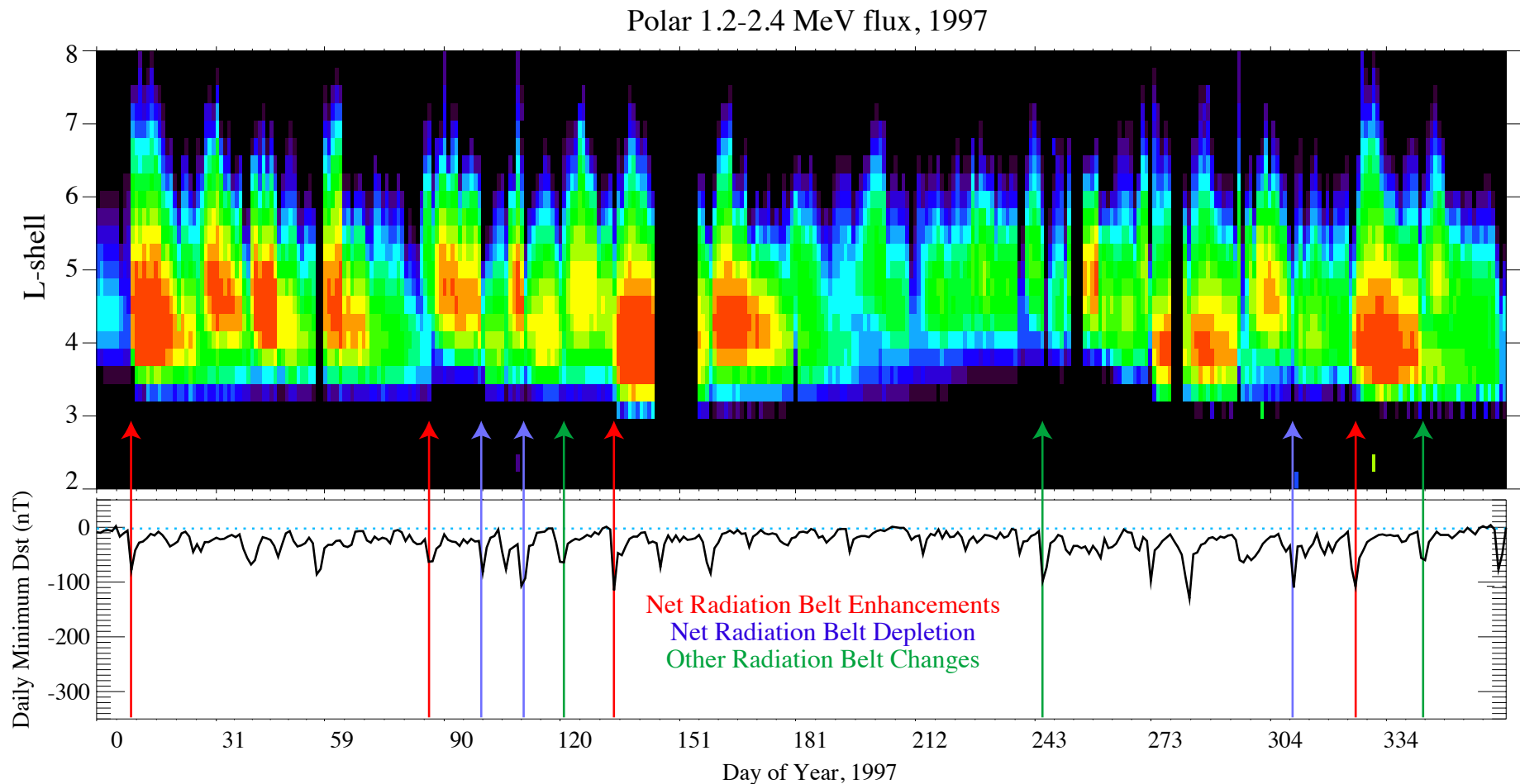
...and now



Radiation belts - Slot region

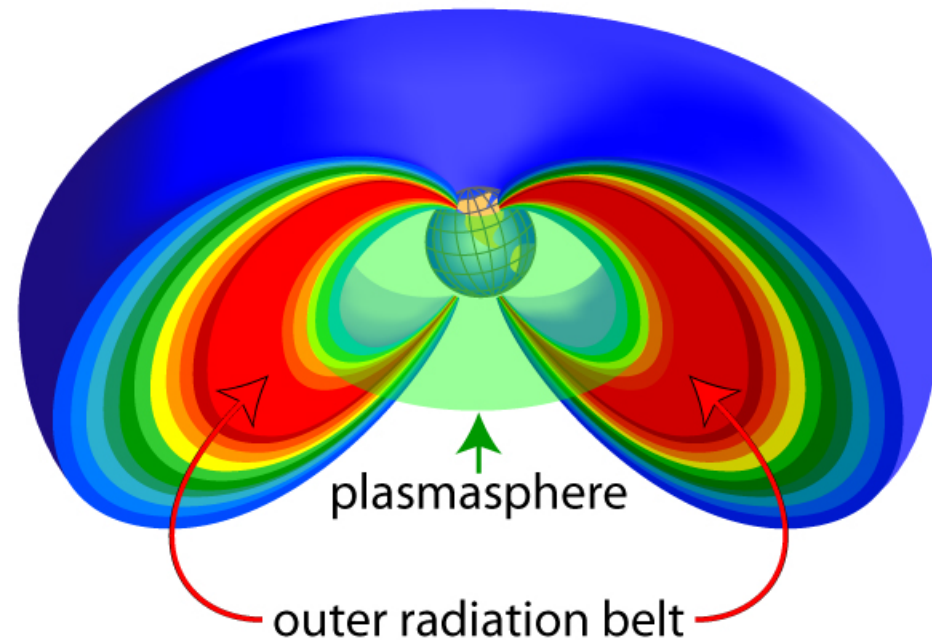


Van Allen Belt Dynamics

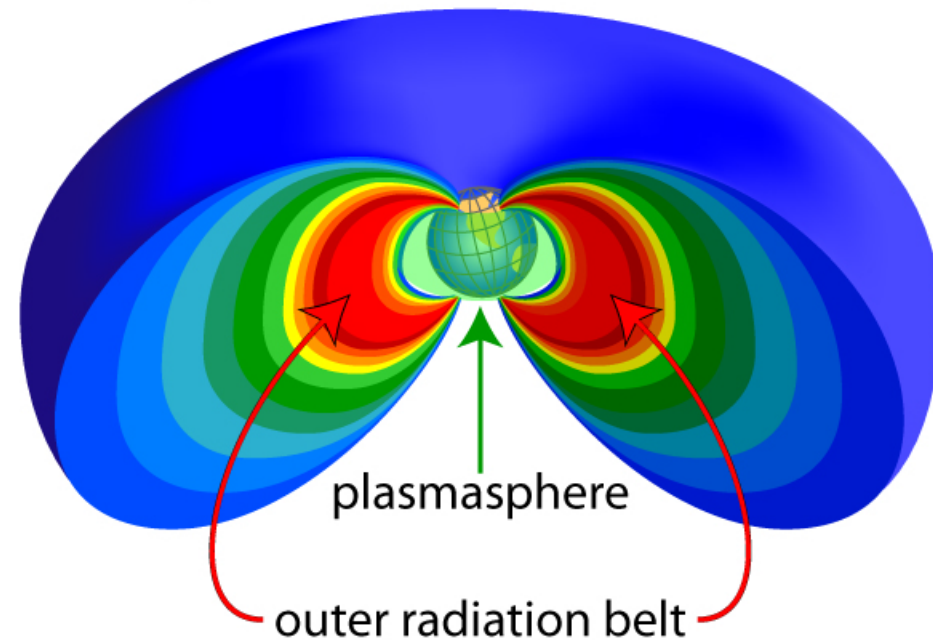


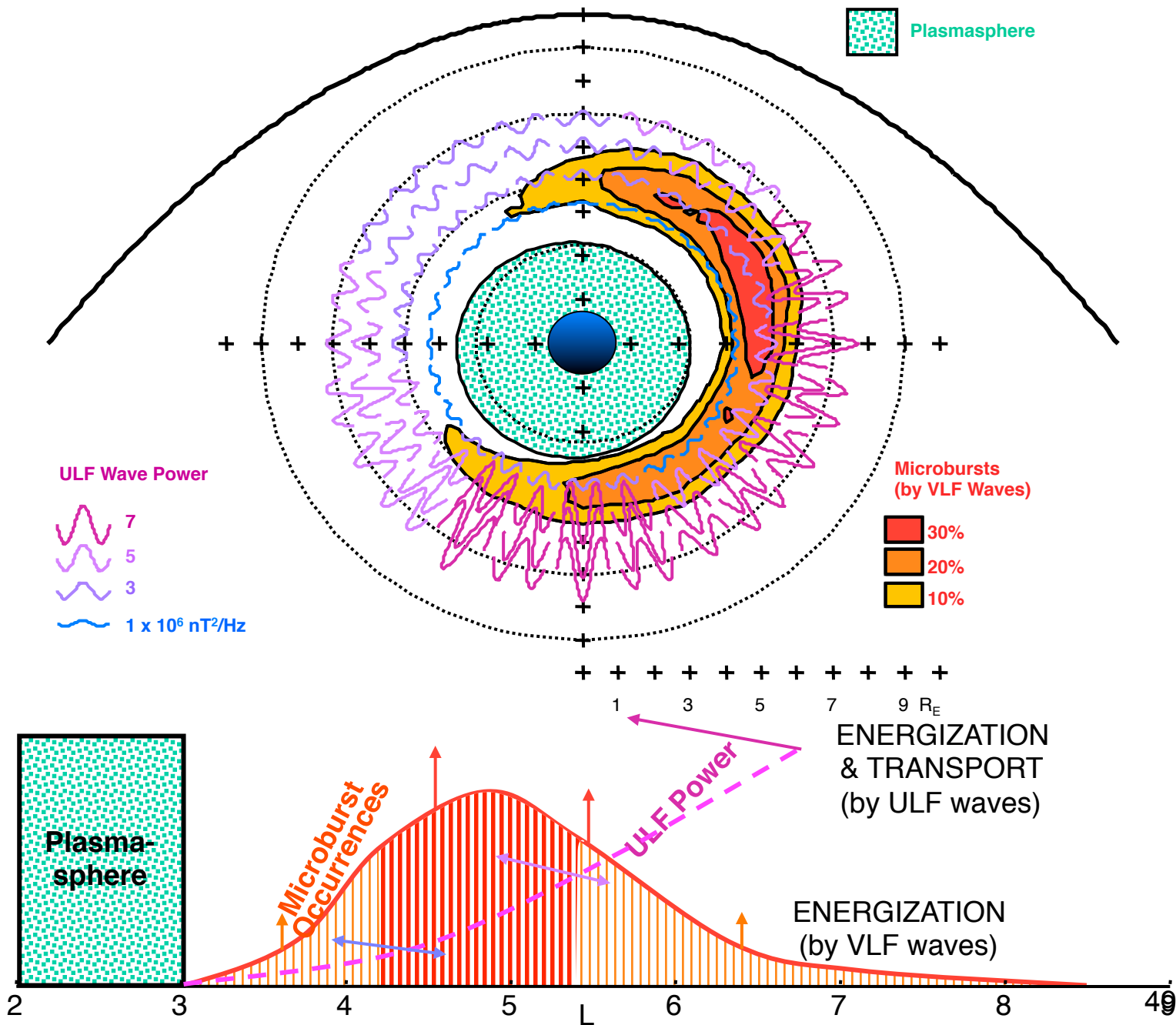
Van Allen Belt Dynamics

a. Normal plasmasphere/radiation belt location under typical conditions

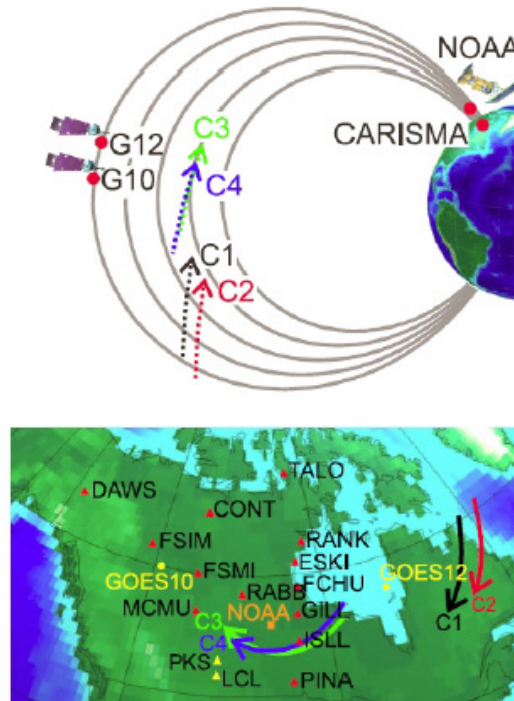
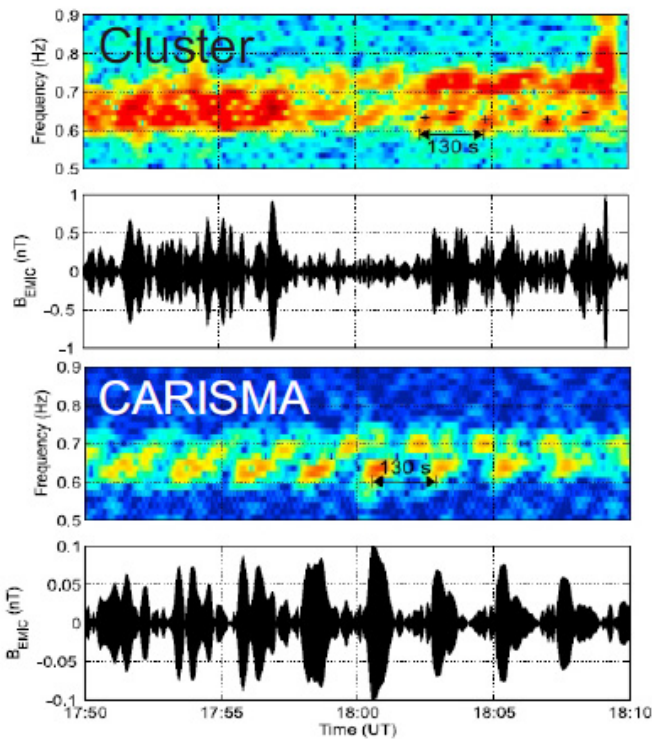


b. Distorted plasmasphere/radiation belt during October/November 2003 storm

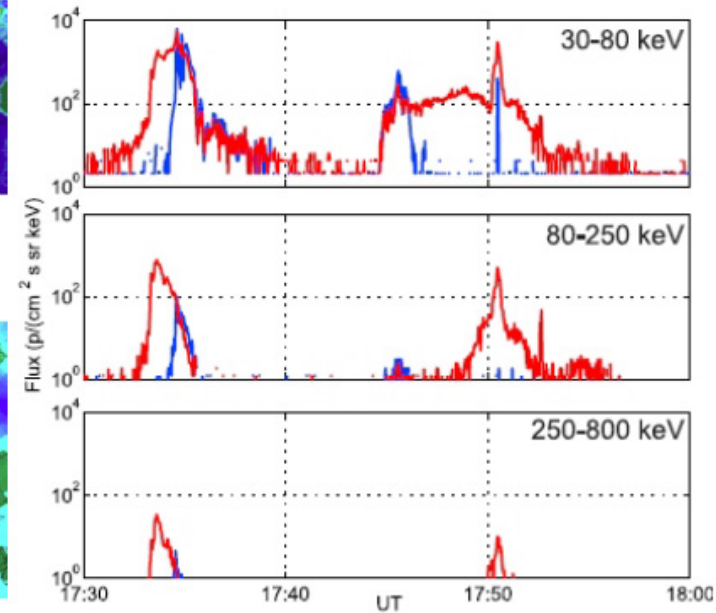




EMIC-related loss of energetic particles

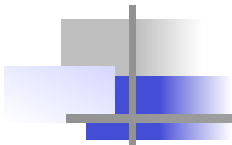


Proton precipitation on NOAA





Ring Current



Single most defining feature:

Global Geomagnetic Field Depression

which can be explained

through the diamagnetic effect

of a giant (ring) current flowing around the Earth

The Ring Current

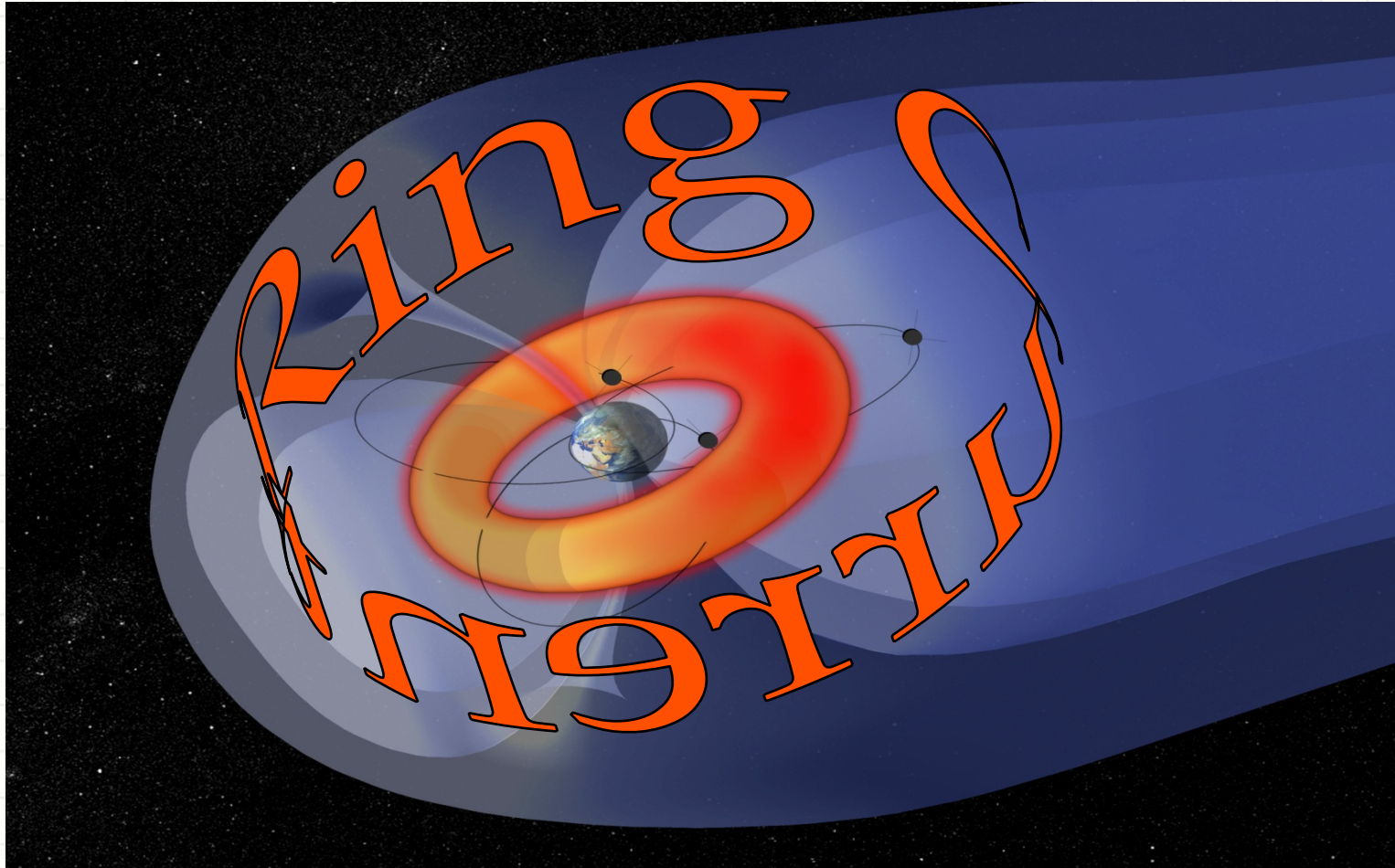
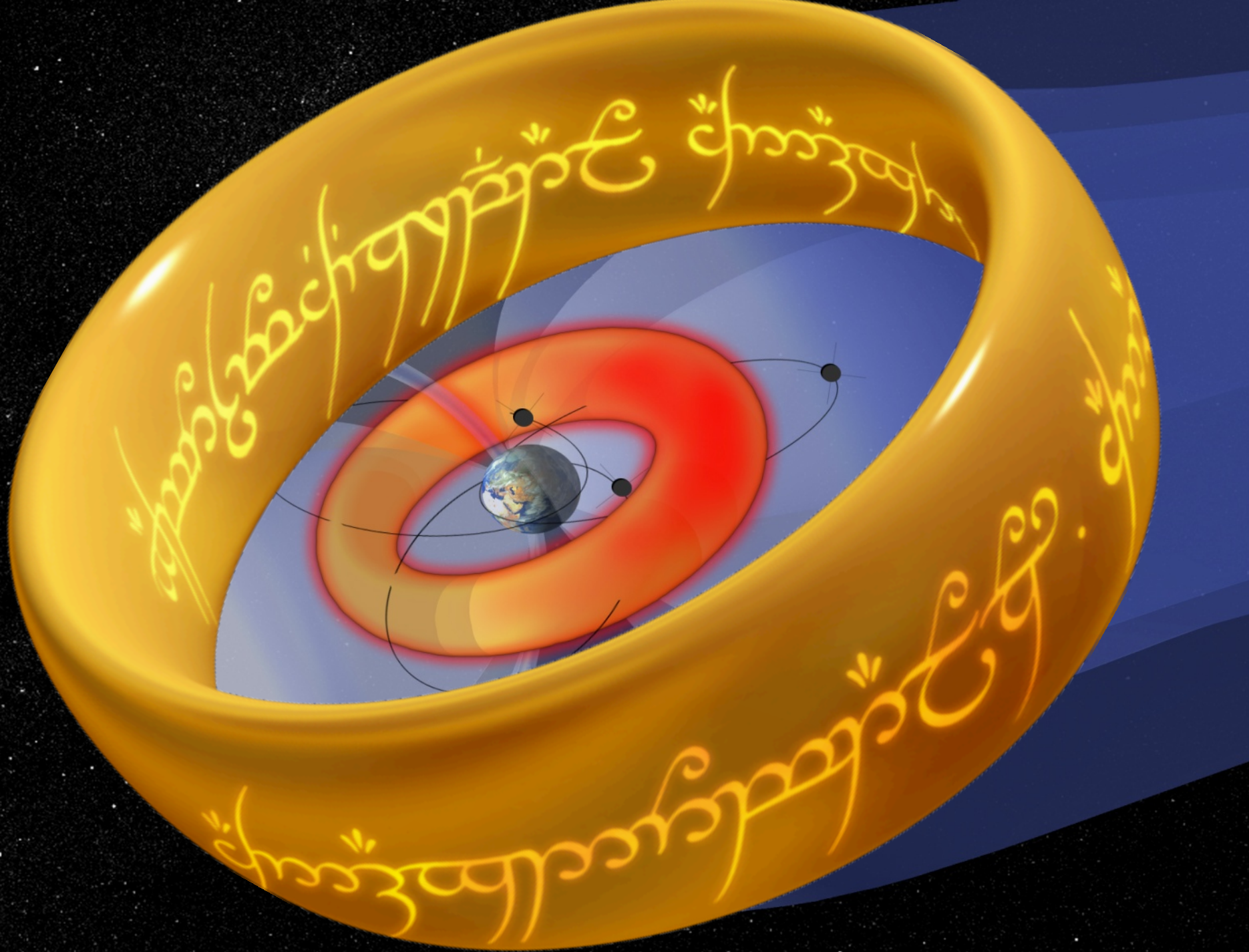


Image courtesy Hannu Koskinen (FMI)



THE INTERRELATIONSHIP OF MAGNETOSPHERIC PROCESSES

VYTENIS M. VASYLIUNAS

*Dept. of Physics and Center for Space Research, Massachusetts Institute of Technology,
Cambridge, Mass., U.S.A.*

“One Ring to rule them all . . .”
J. R. R. TOLKIEN

1. Introduction

Convection of plasma in the magnetosphere is one of the major aspects of magnetospheric dynamics. Attempts during the past 10 yr to understand this complicated phenomenon have led to a sequence of theoretical models of constantly increasing sophistication (see, for example, Axford (1969)). Most of these models have been

Vasyliunas, in *Earth's Magnetospheric Processes*,
Astrophysics and Space Science Library Vol. 32, 1972

THE INTERRELATIONSHIP OF MAGNETOSPHERIC PROCESSES

VYTENIS M. VASYLIUNAS

*Dept. of Physics and Center for Space Research, Massachusetts Institute of Technology,
Cambridge, Mass., U.S.A.*

“One Ring to rule them all . . .”
J. R. R. TOLKIEN

1. Introduction

Convection of plasma in the magnetosphere is one of the major aspects of magnetospheric dynamics. Attempts during the past 10 yr to understand this complicated phenomenon have led to a sequence of theoretical models of constantly increasing sophistication (see, for example, Axford (1969)). Most of these models have been

Vasyliunas, in *Earth's Magnetospheric Processes*
Astrophysics and Space Science Library Vol. 32, 1972

THE LORD OF THE RINGS

PART
I

The Fellowship



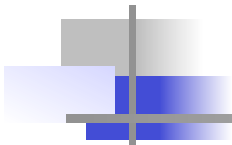
of the
Ring

by

J.R.R. TOLKIEN

One Ring

John Ronald Reuel Tolkien

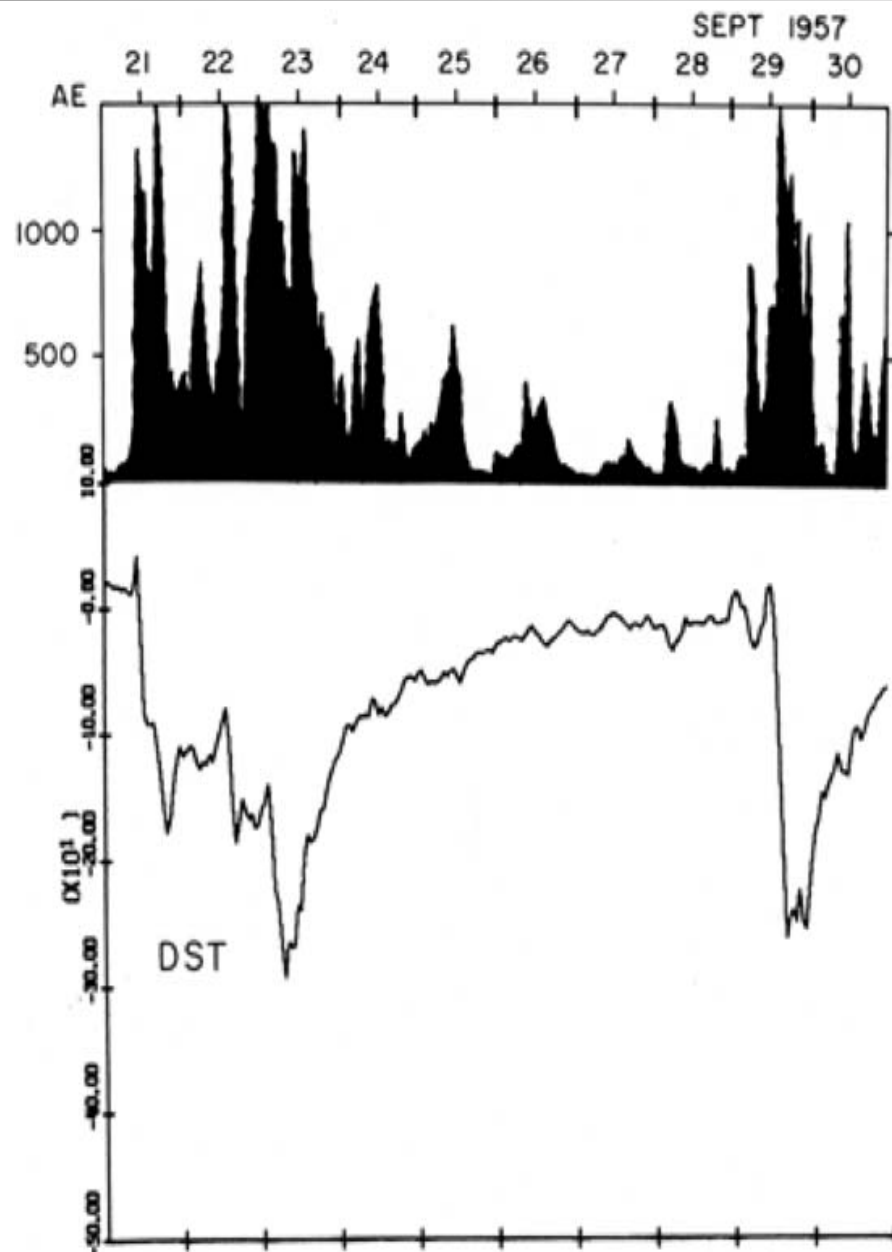


Storm-substorm relationship


$$\text{Storm} = \sum_i \text{Substorms}_i$$

Ring current =
Accumulative result
of a series of substorm ion injections

Sydney Chapman, Syun-Ichi Akasofu

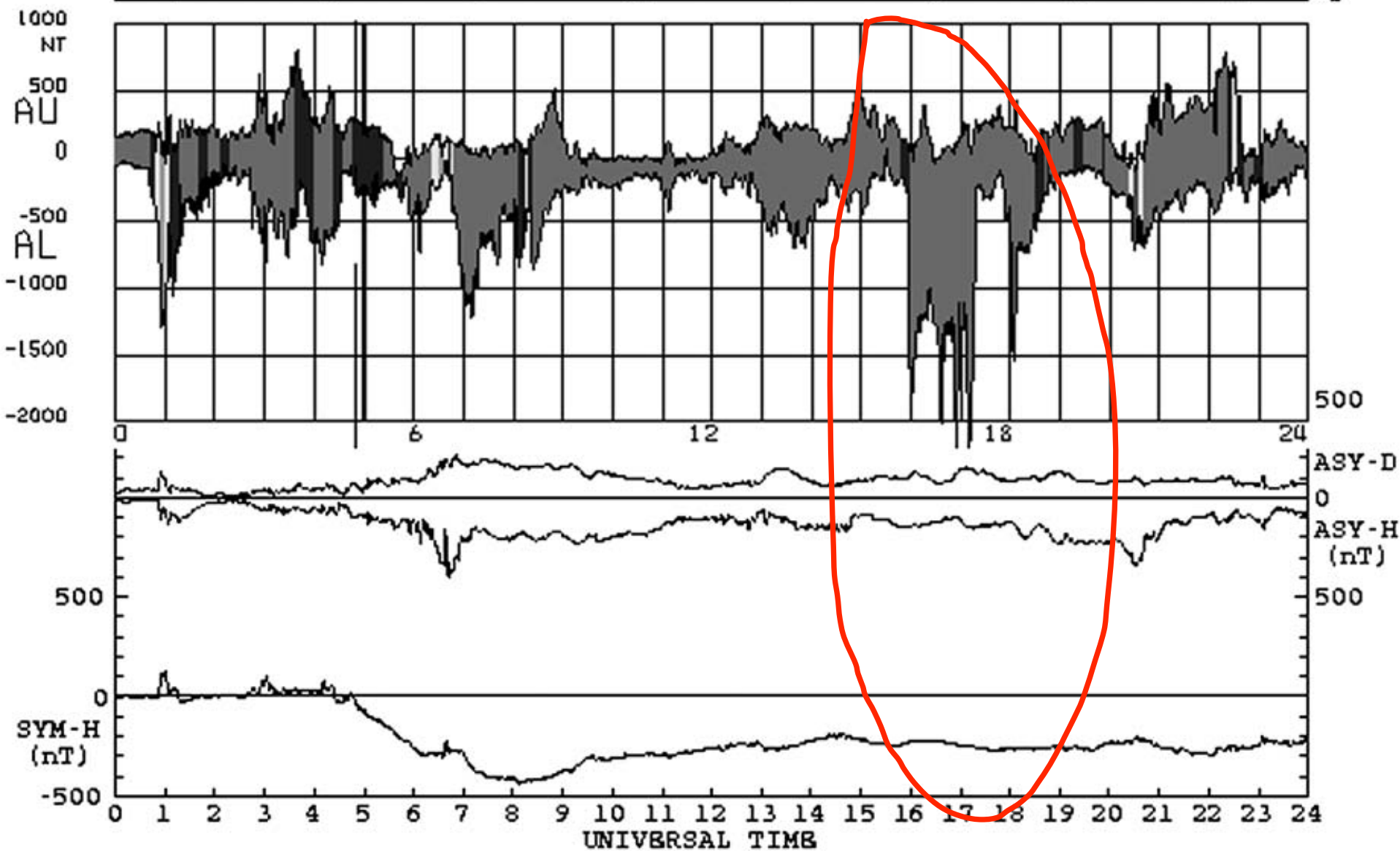


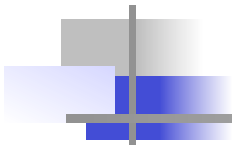
AU/AL/ASY/SYM INDICES MAR 31 2001

AE AND ASYM 1-MIN. VALUES

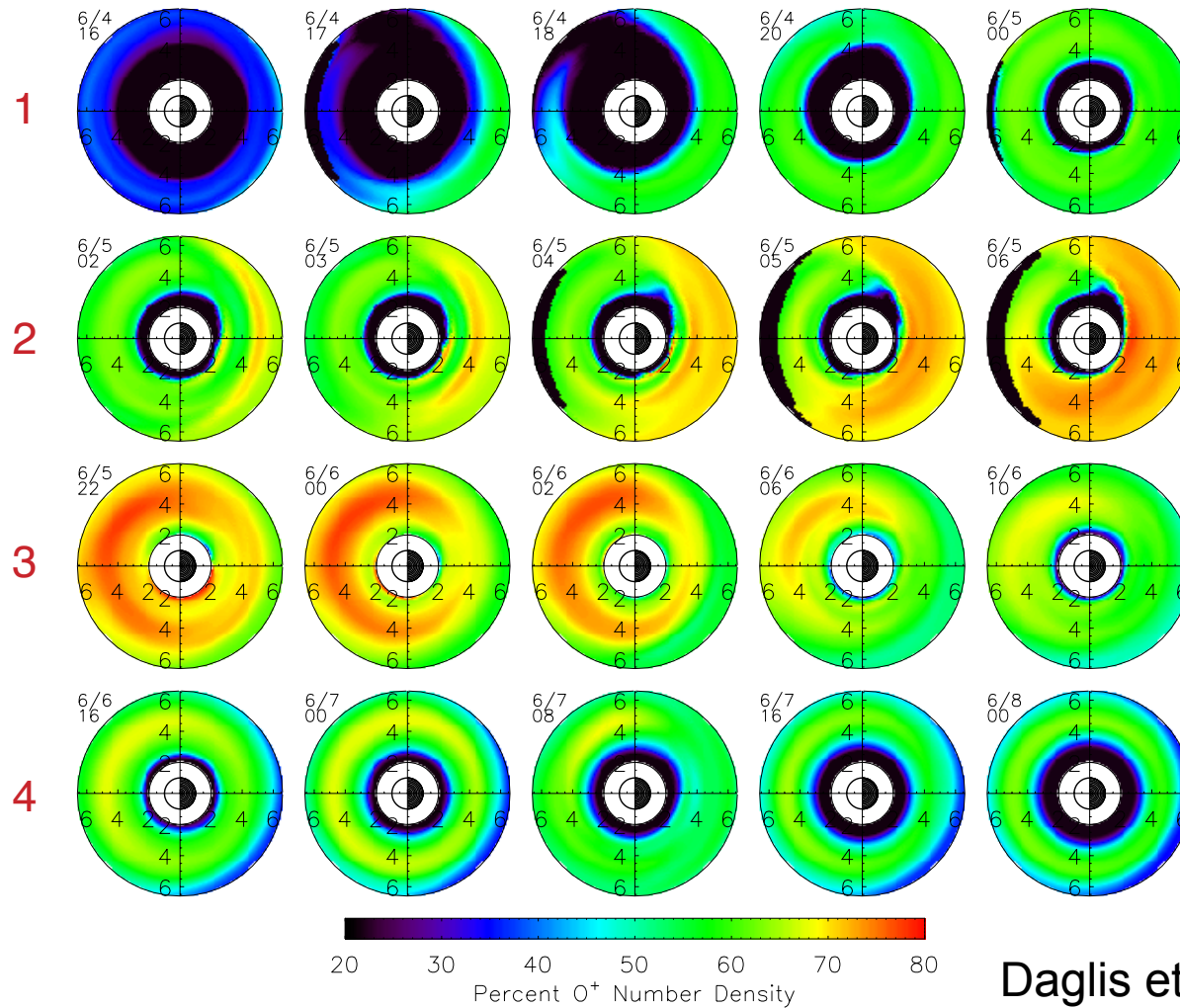
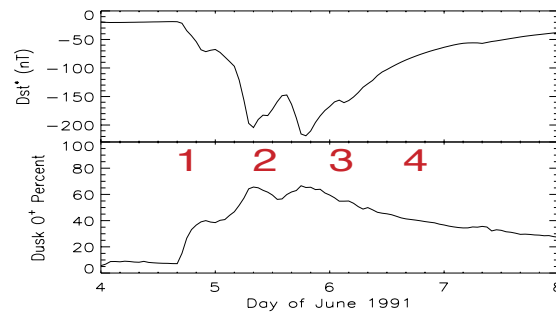
WDC KYOTO

7- 9- 9- 6+ 7 8 8+ 7+ Kp

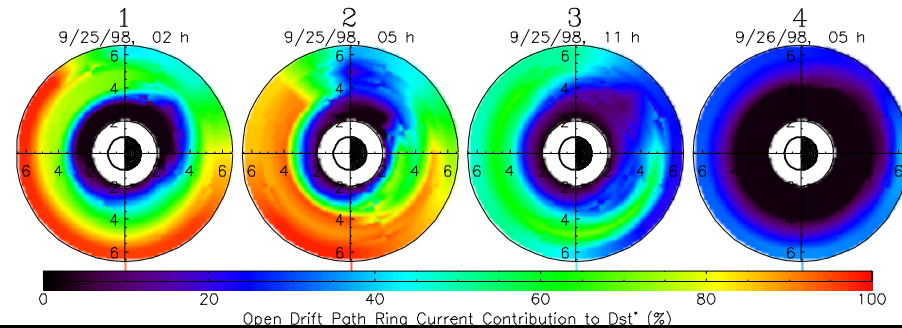
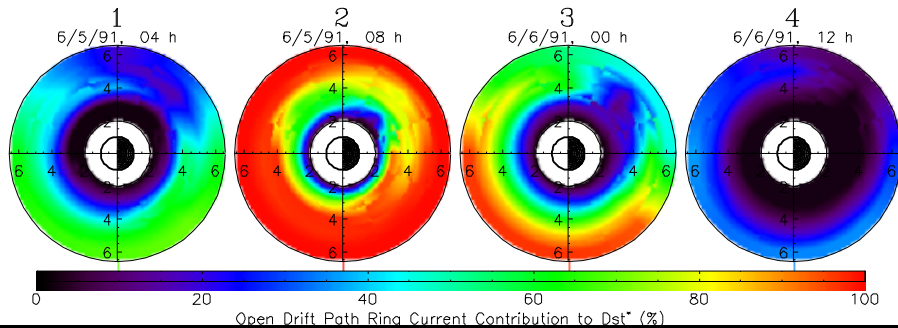
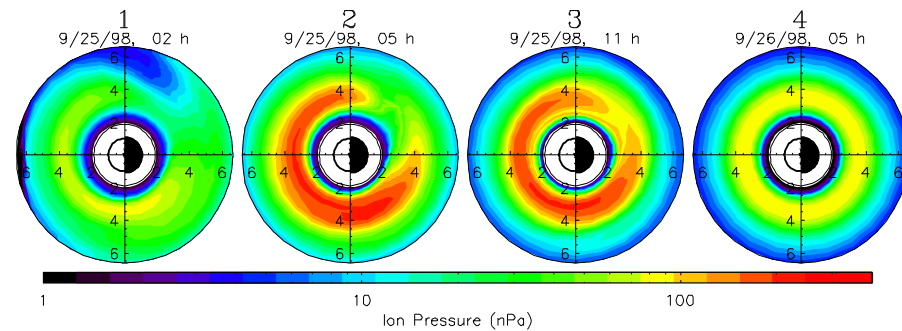
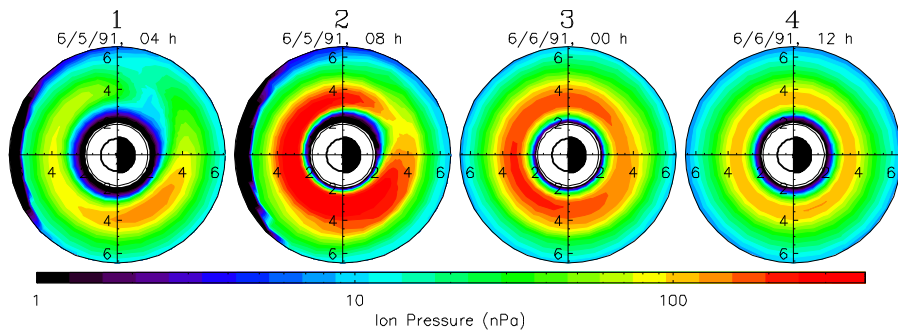
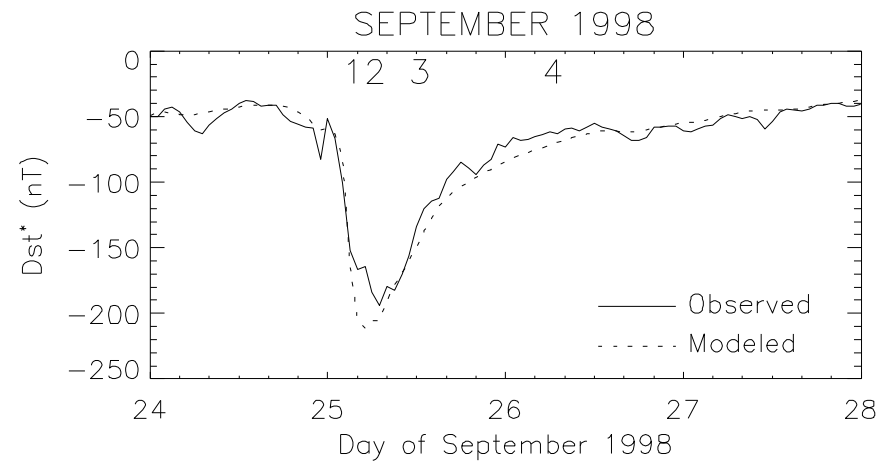
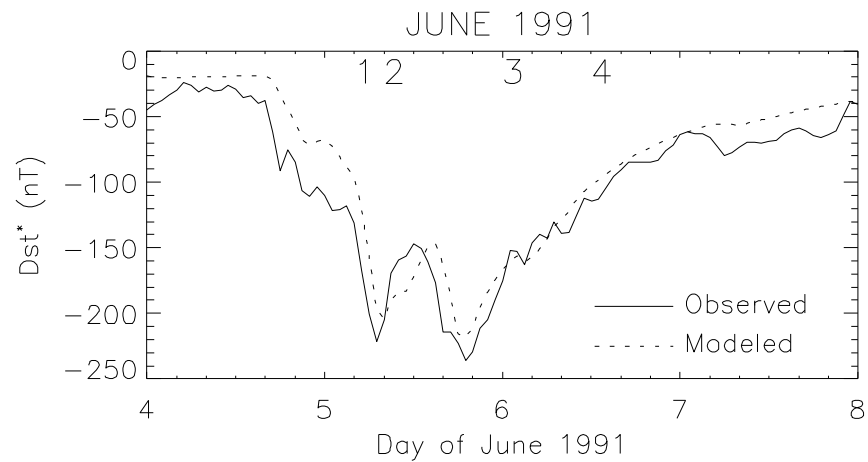




Substorms do however
influence / define
plasma composition
in the magnetosphere
and specifically
in the inner magnetosphere
and in the ring current



Dynamic evolution - RC [a]symmetry



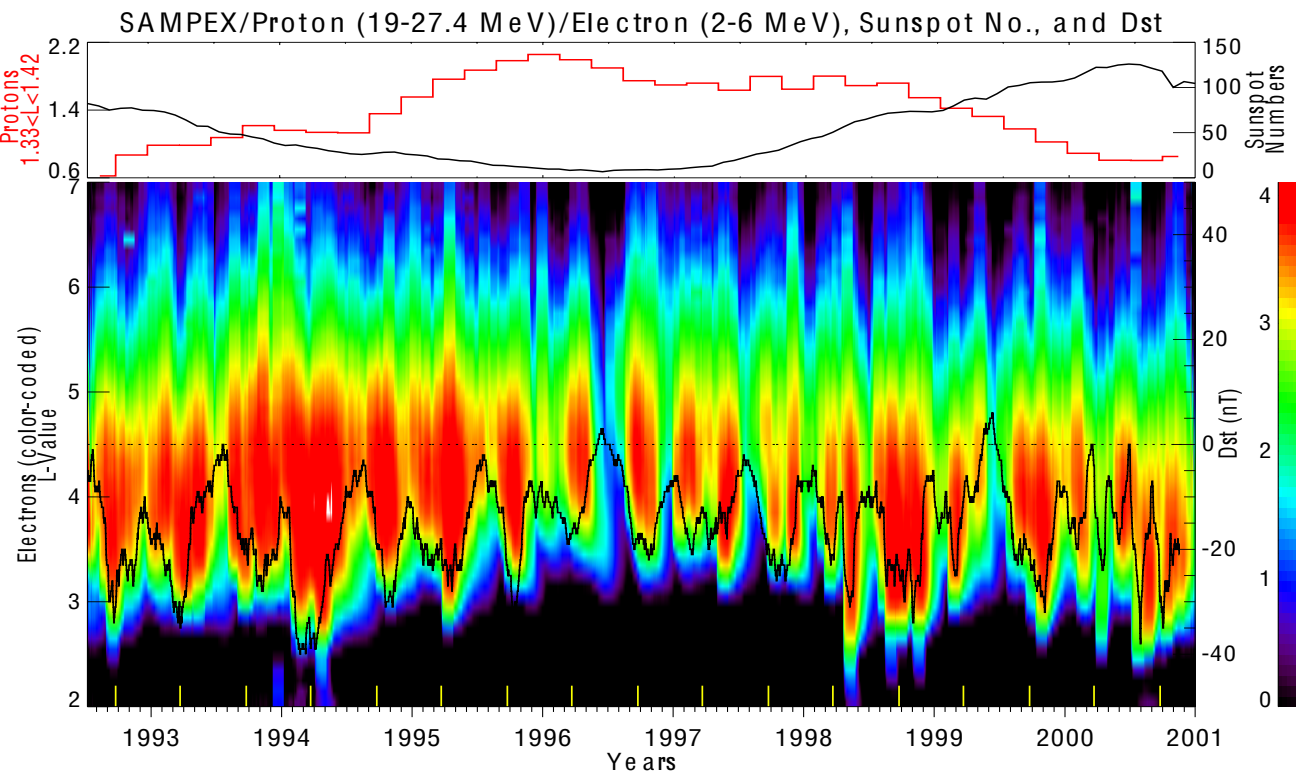
Ring current asymmetry [Daglis et al., 2003]



Van Allen belt dynamics and geomagnetic storms

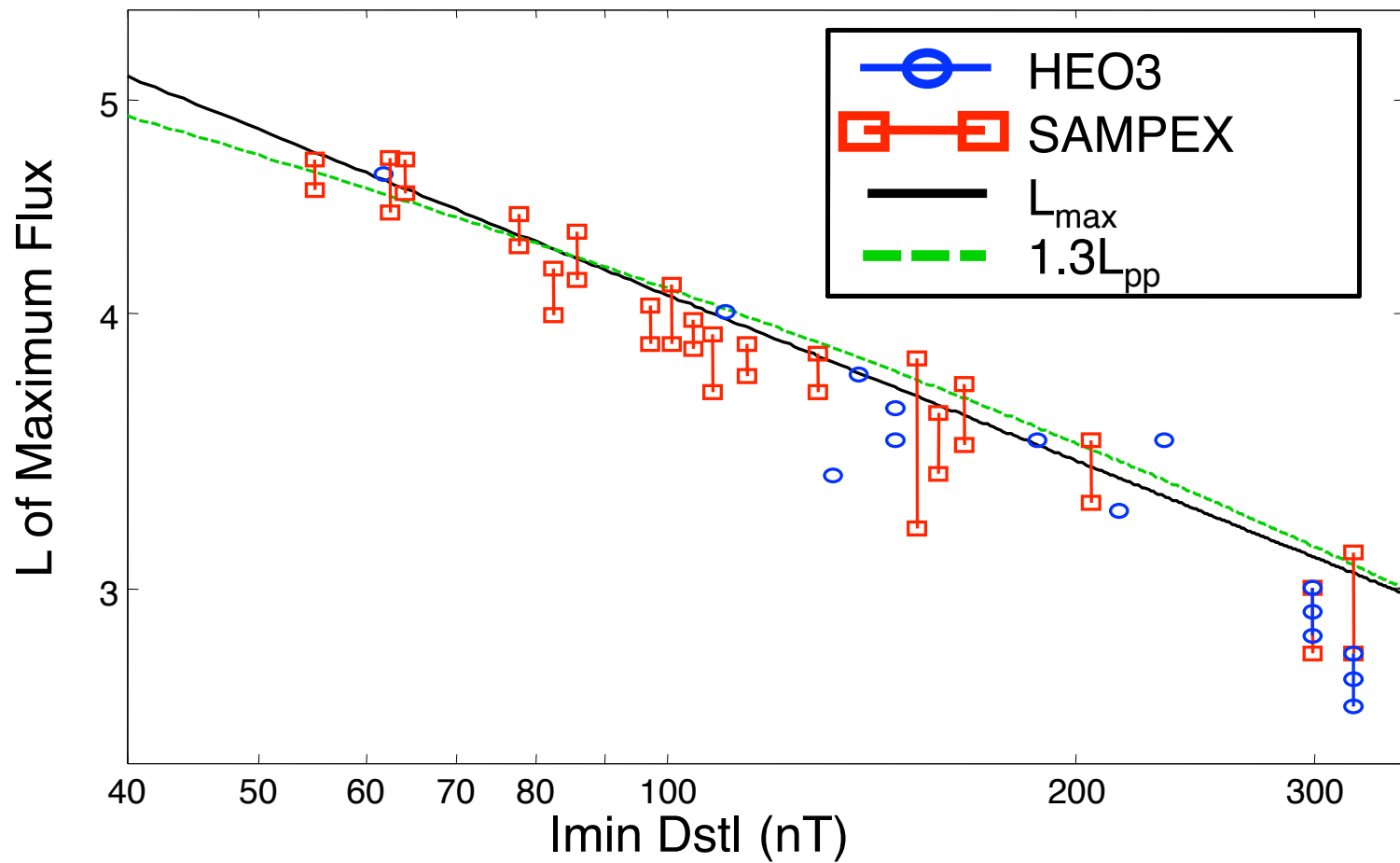
Flux variability in the radiation belts

The radiation belts exhibit substantial variation in time:

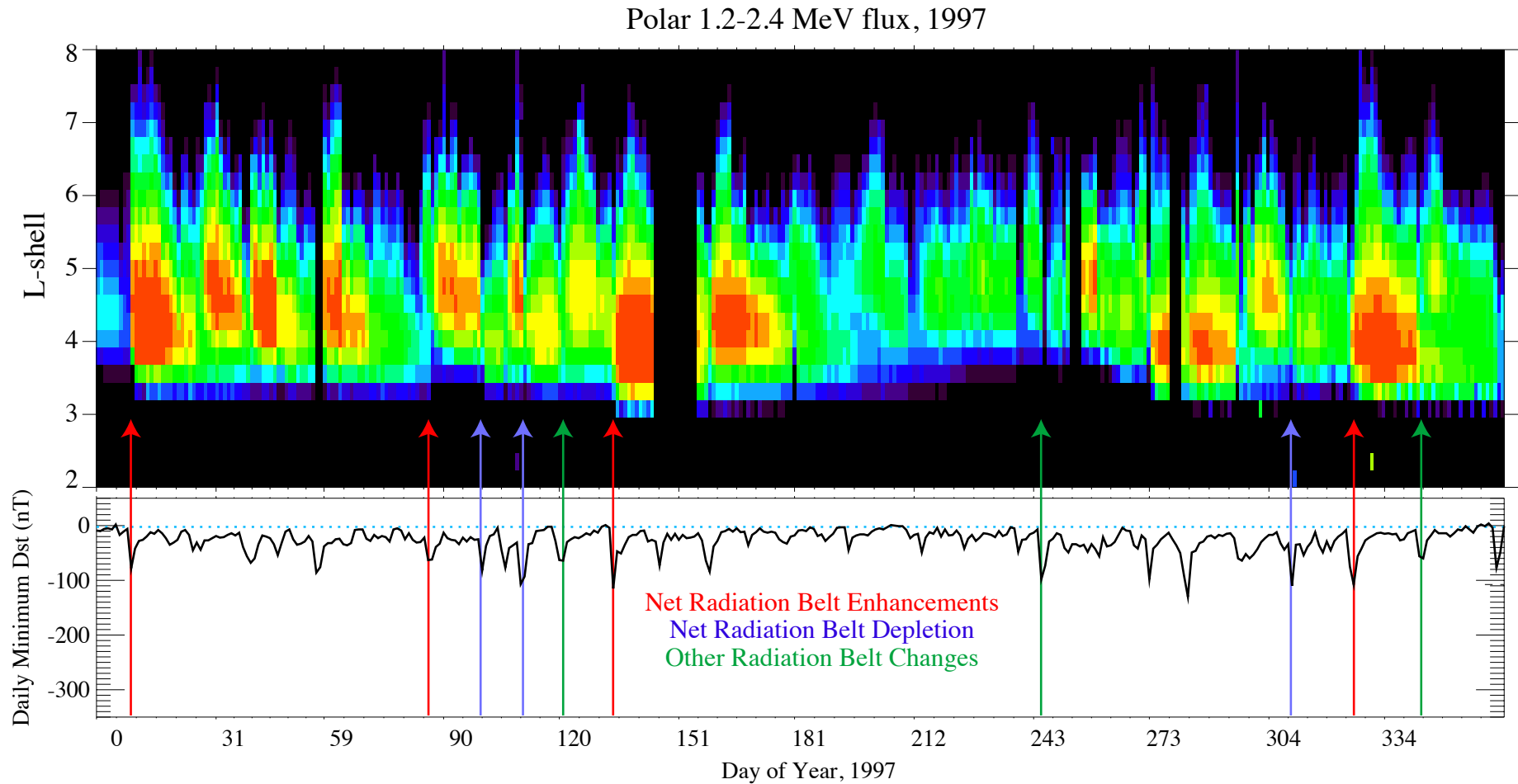


- Solar cycle: years
- Season: Months
- Solar rotation: 13-27 days
- Storm recovery: days
- Storm main phase: hours
- SSC: minutes

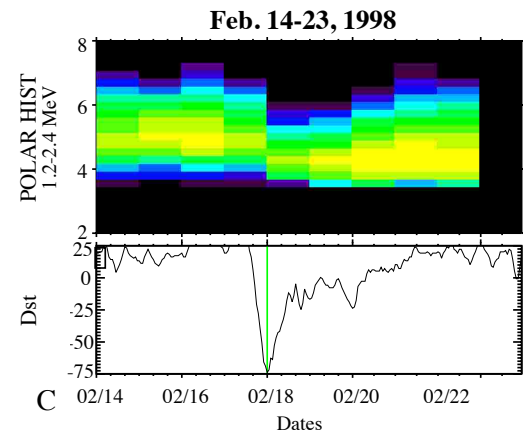
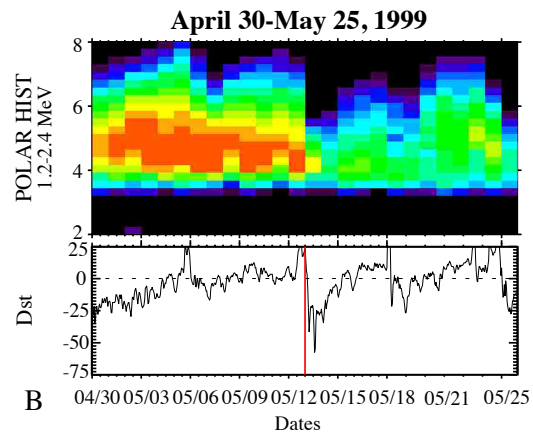
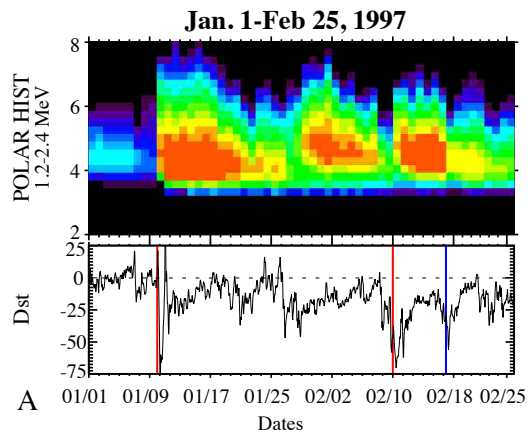
Geospace Storms and Radiation Belts



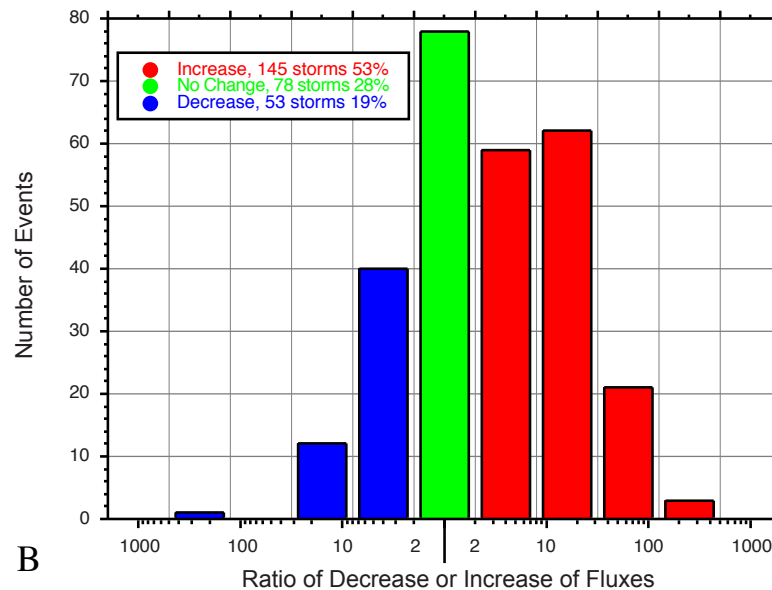
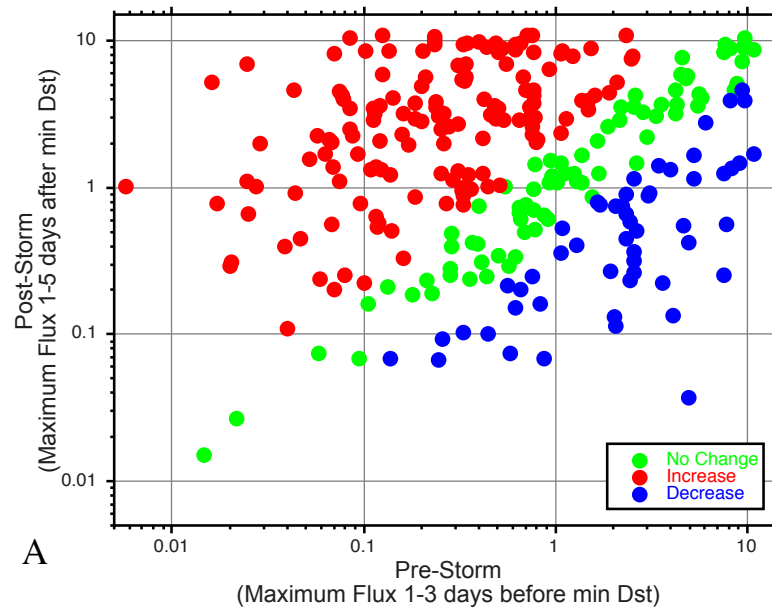
Geospace Storms and Radiation Belts



Magnetic Storms and Radiation Belts

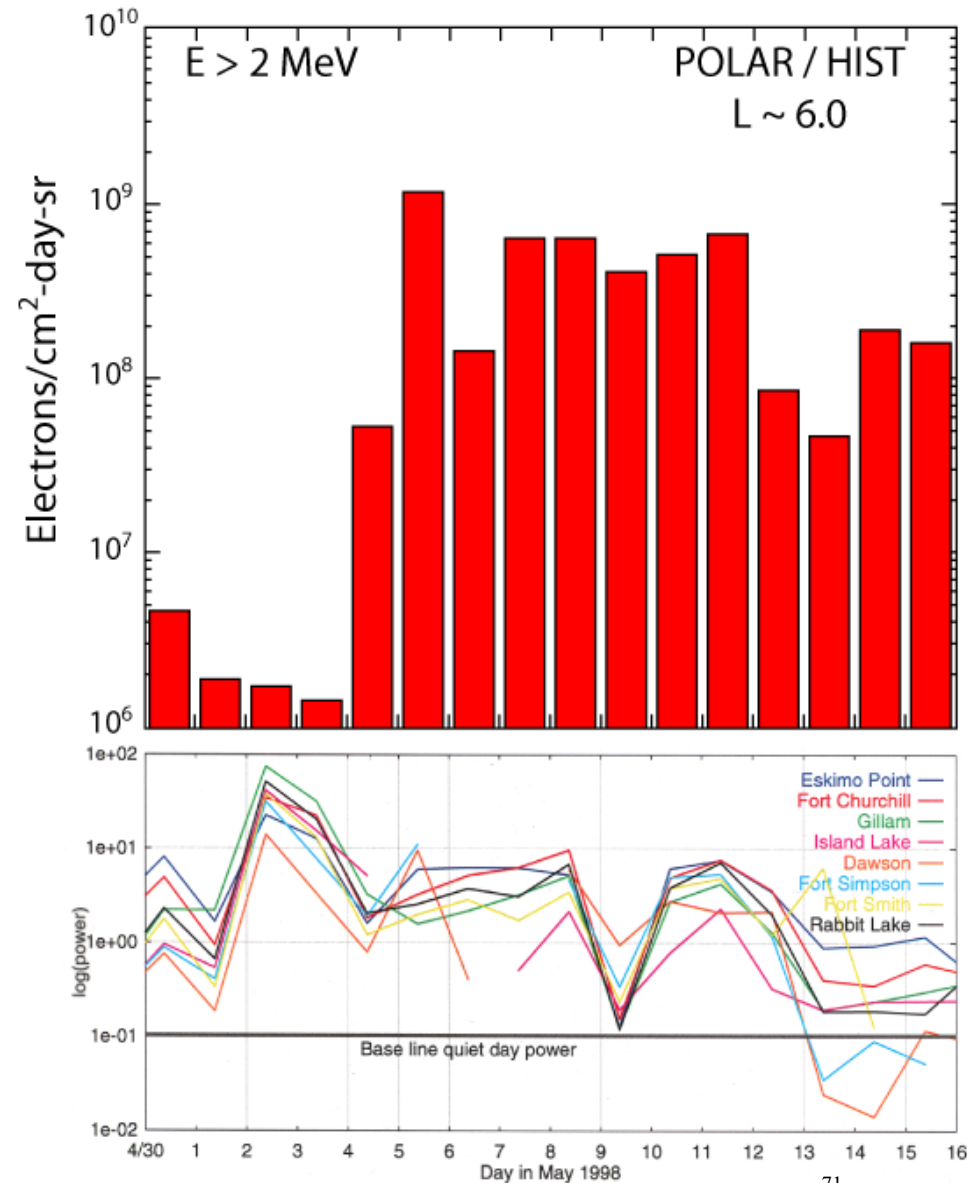


Geospace Storms and Radiation Belts

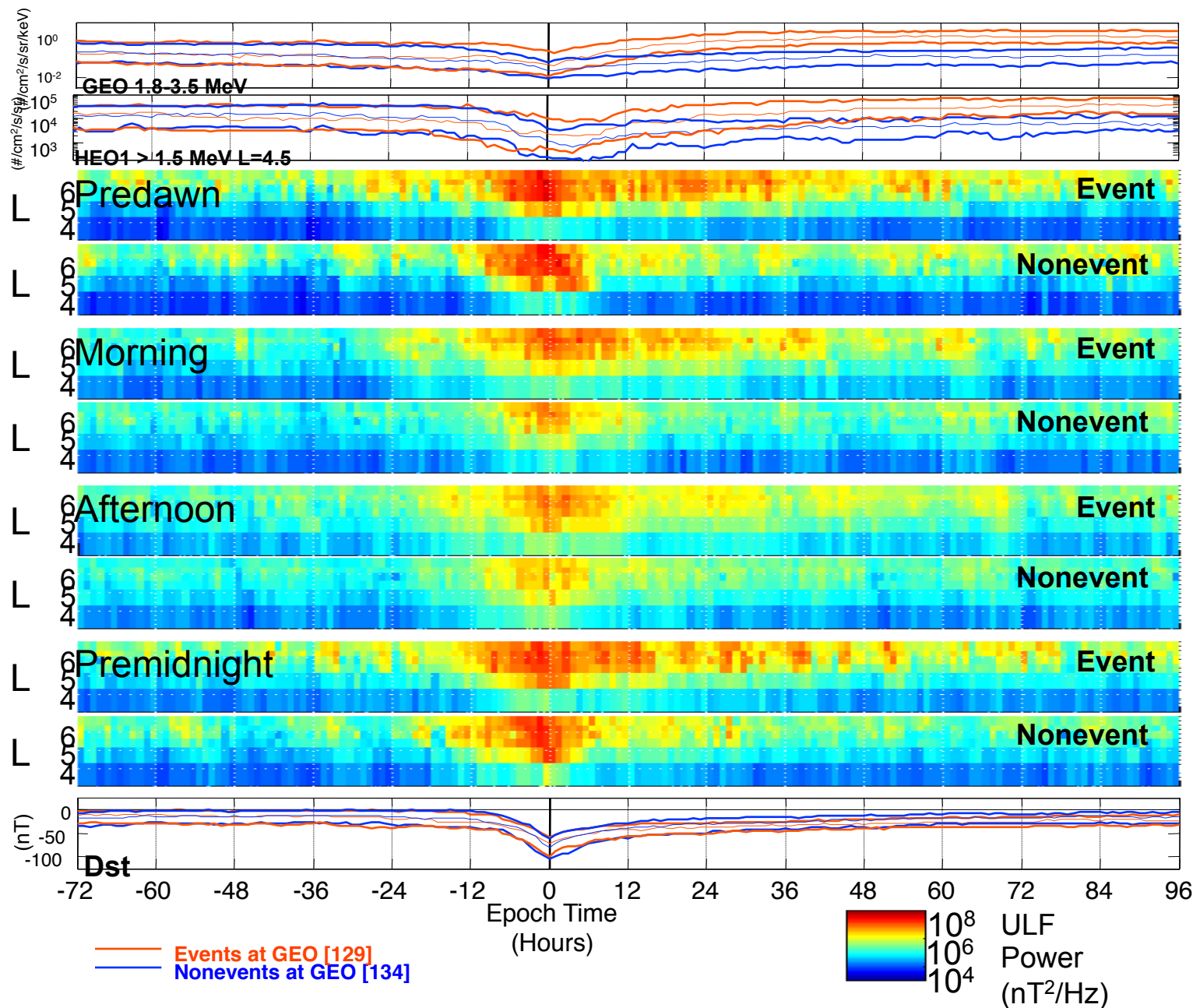


Geospace Storms and Radiation Belts

Association of MeV
electrons with ULF
wave power increase
[Baker & Daglis, 2006]



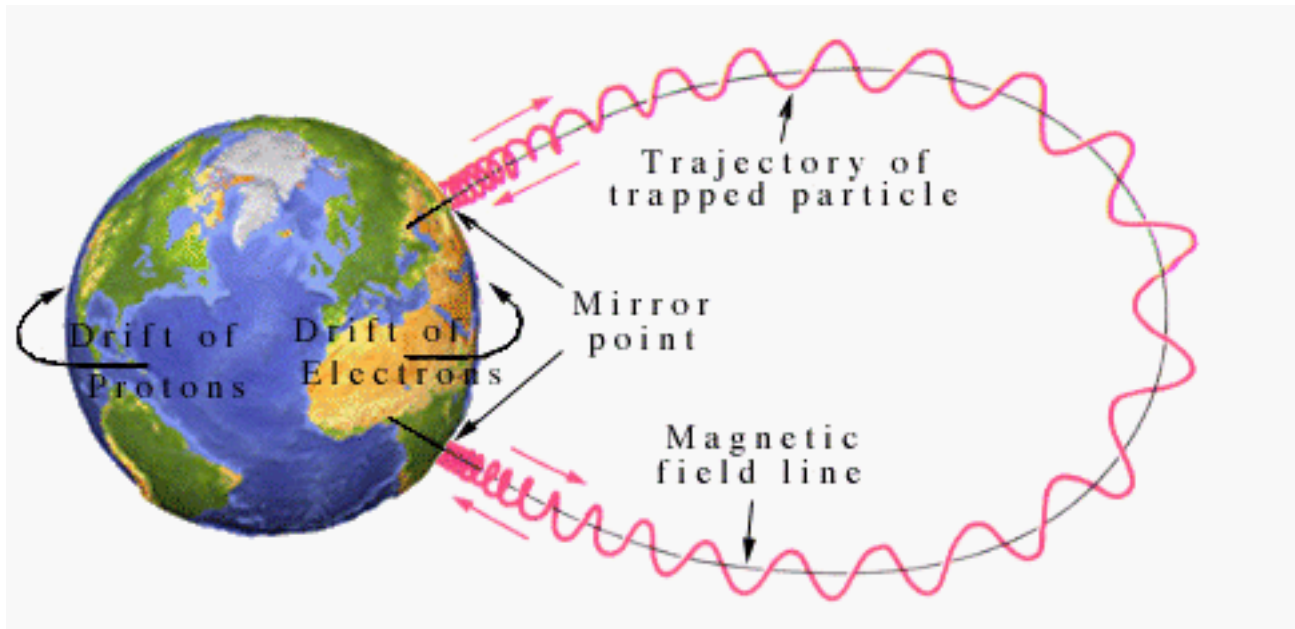
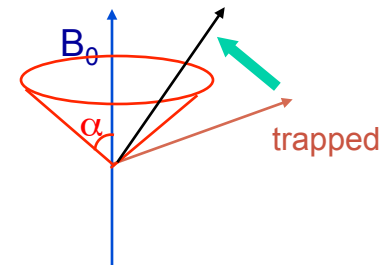
Geospace Storms and Radiation Belts



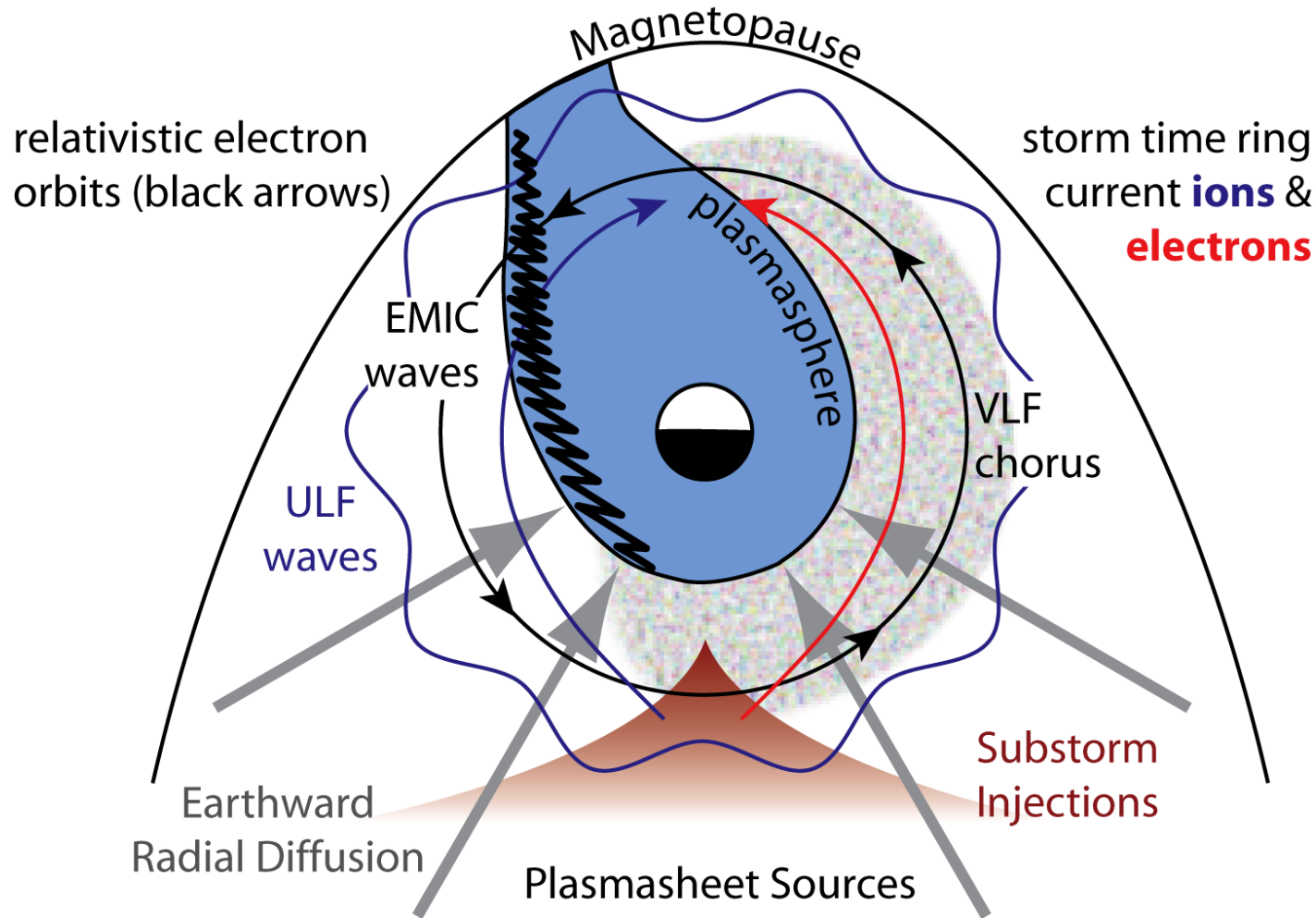
Geospace Storms and Radiation Belts

WPI-PAD CONTROL OF LOSS RATE

ULF/ELF/VLF waves resonate with trapped particles in the magnetosphere causing pitch angle scattering and precipitation.



Geospace Storms and Radiation Belts



Complex and rich relation

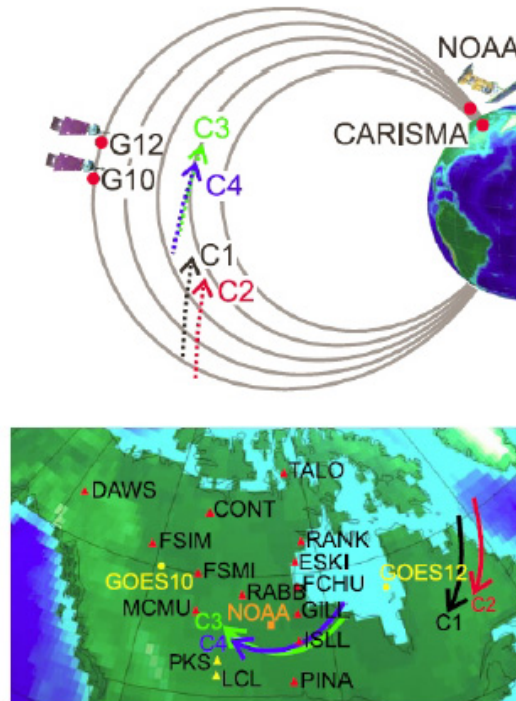
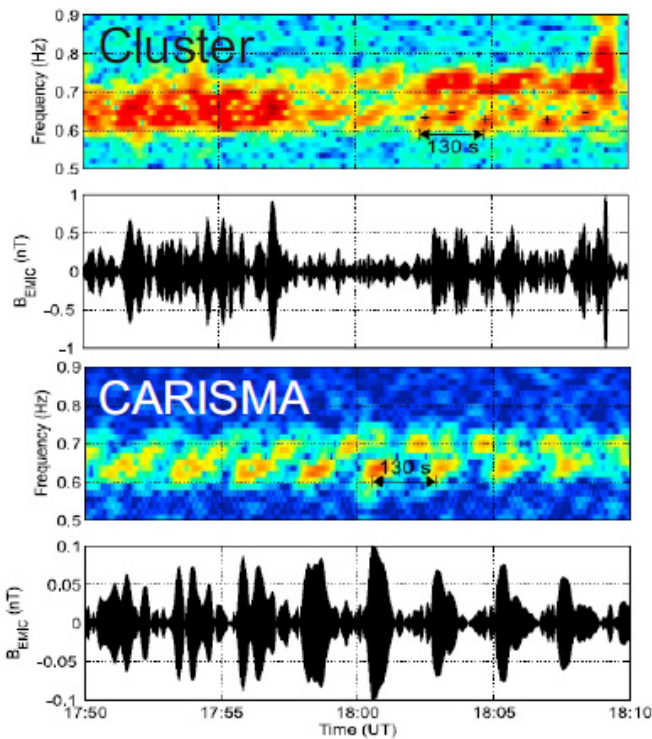
FP7-Space MAARBLE

NOA, ONERA, BAS, IRF, IAP, UofA, UCLA

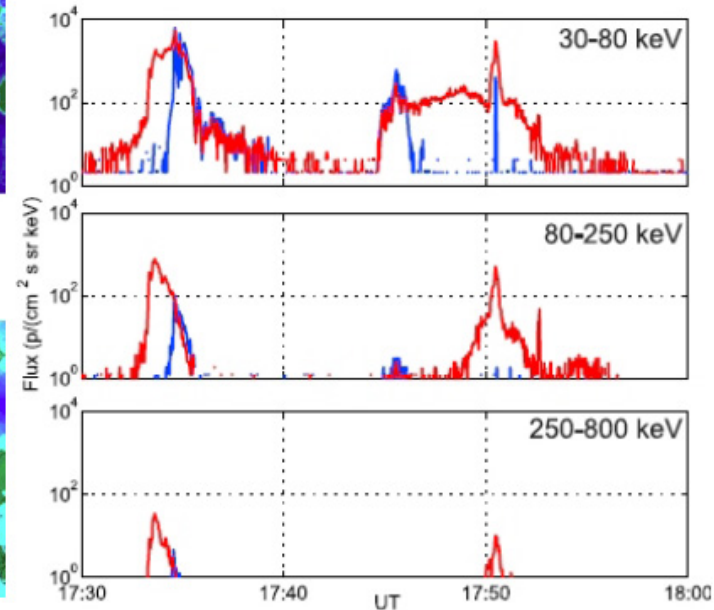


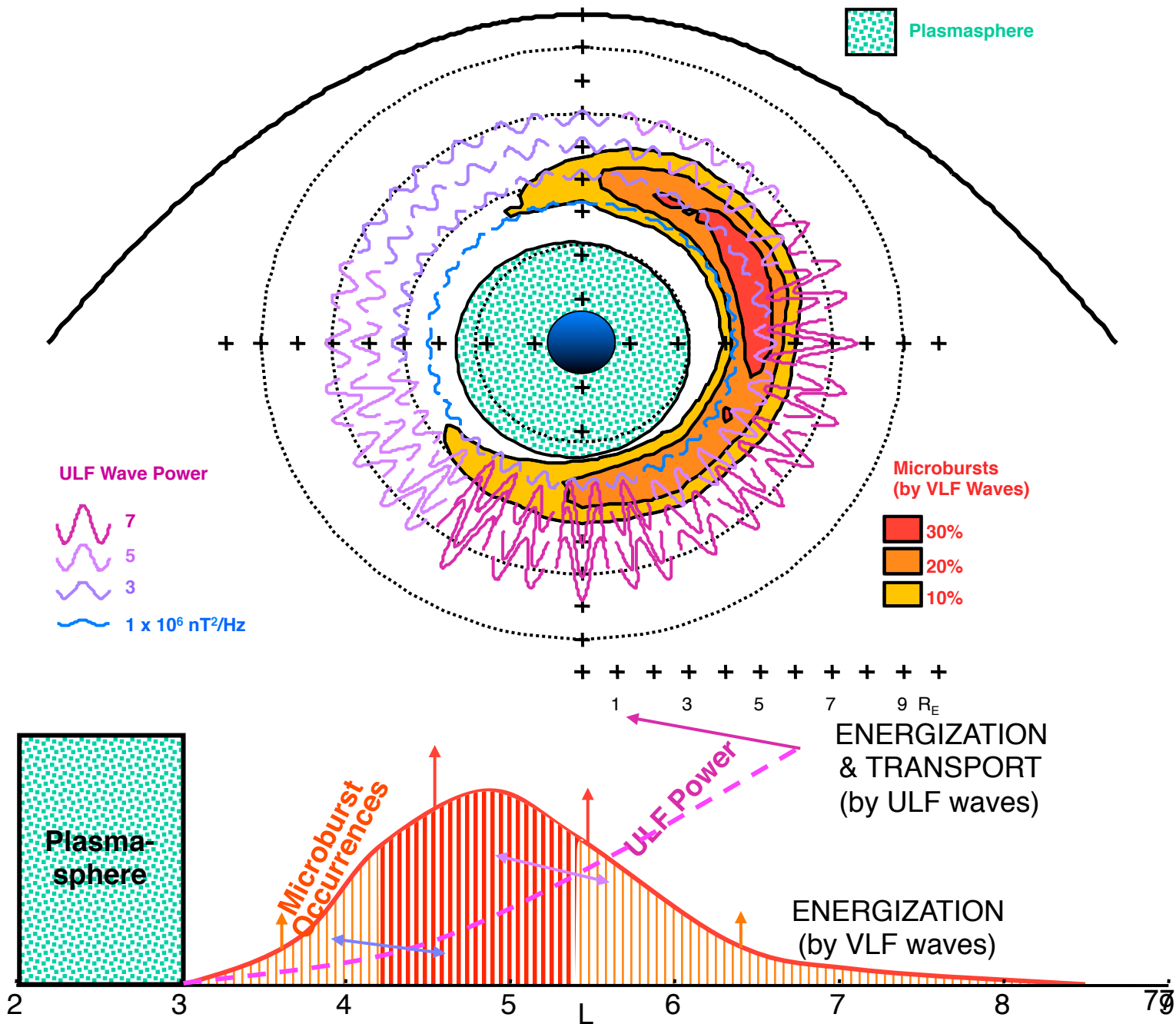
Geospace Storms and Radiation Belts

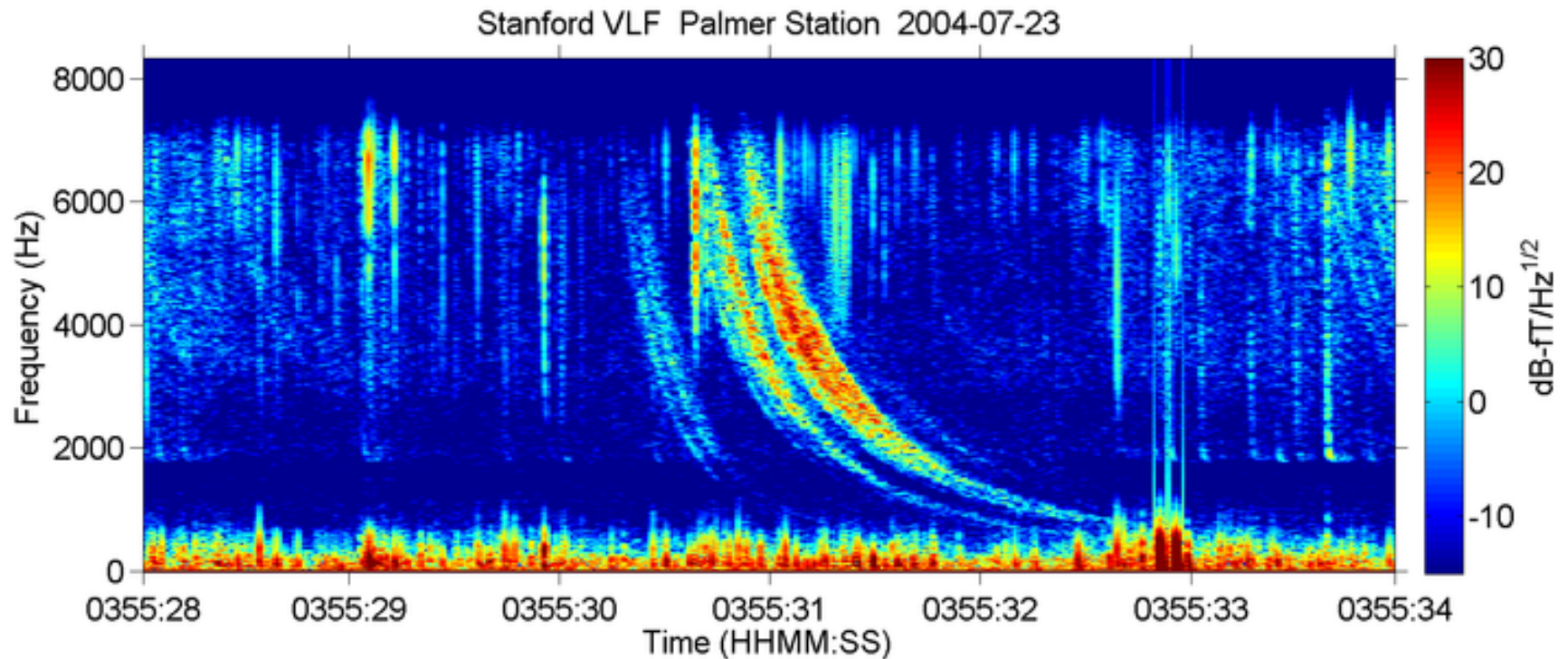
EMIC-related loss of energetic particles



Proton precipitation on NOAA



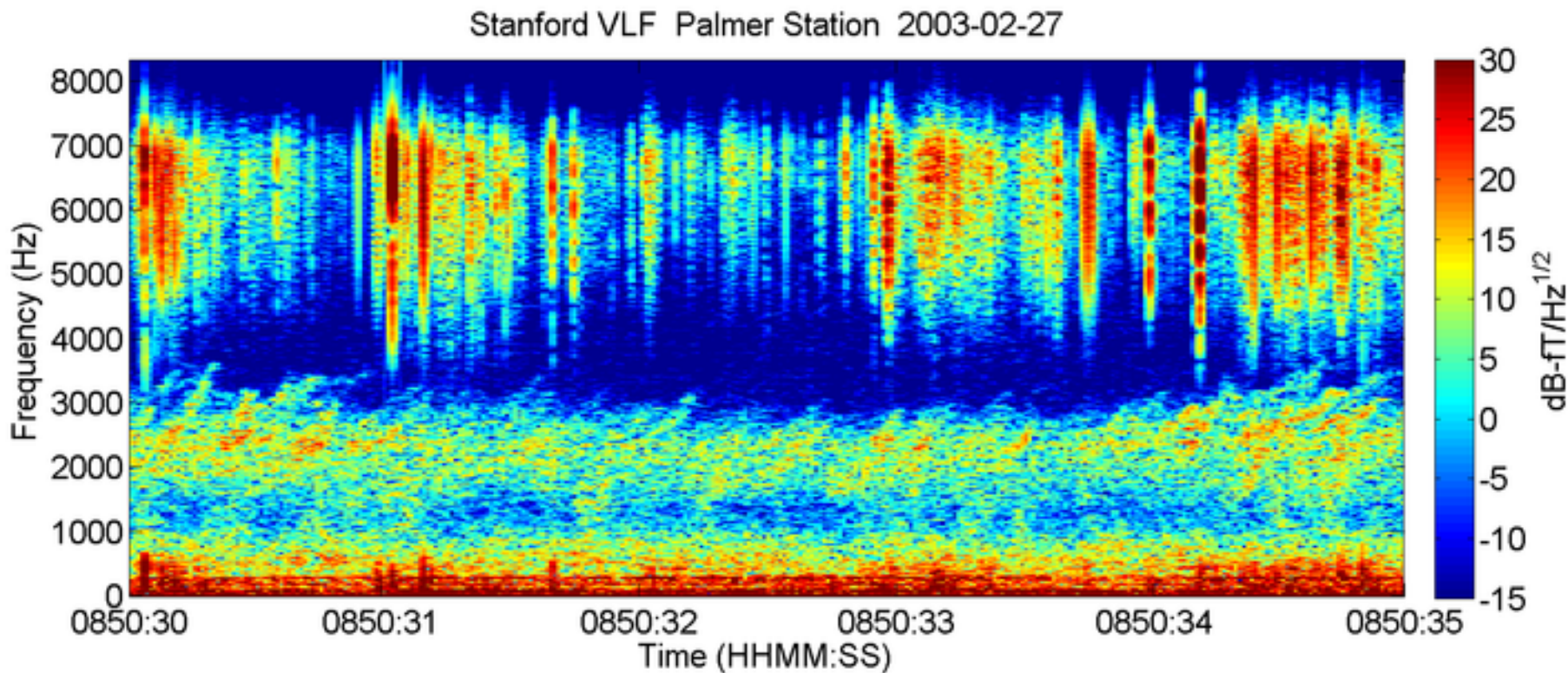




Whistler Waves

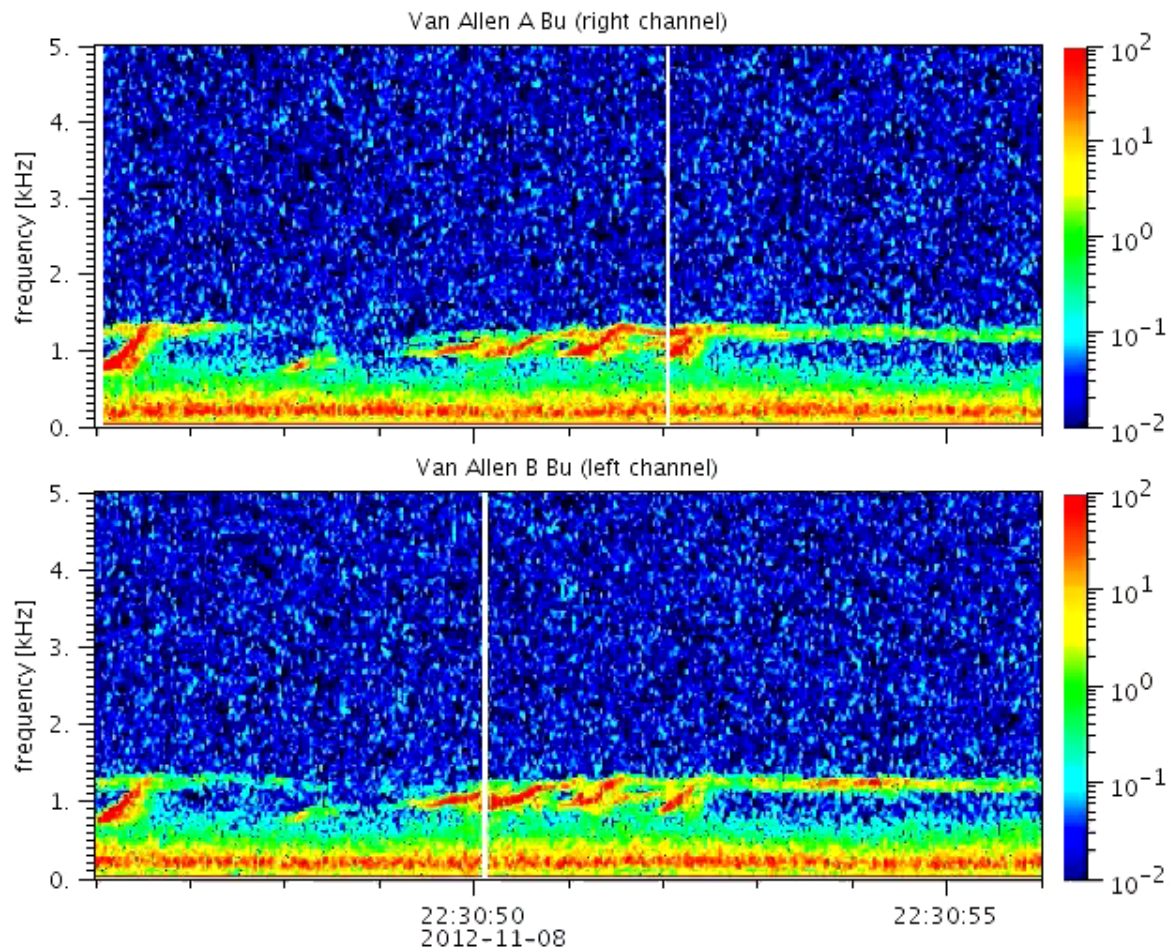
Lightning-produced waves in frequencies 1-30 kHz

Due to the dependence of their dispersion relation to frequency, high-frequency components of the pulse arrive slightly before the low-frequency components.



Chorus

L=4 and L=10, distribution peak near local dawn



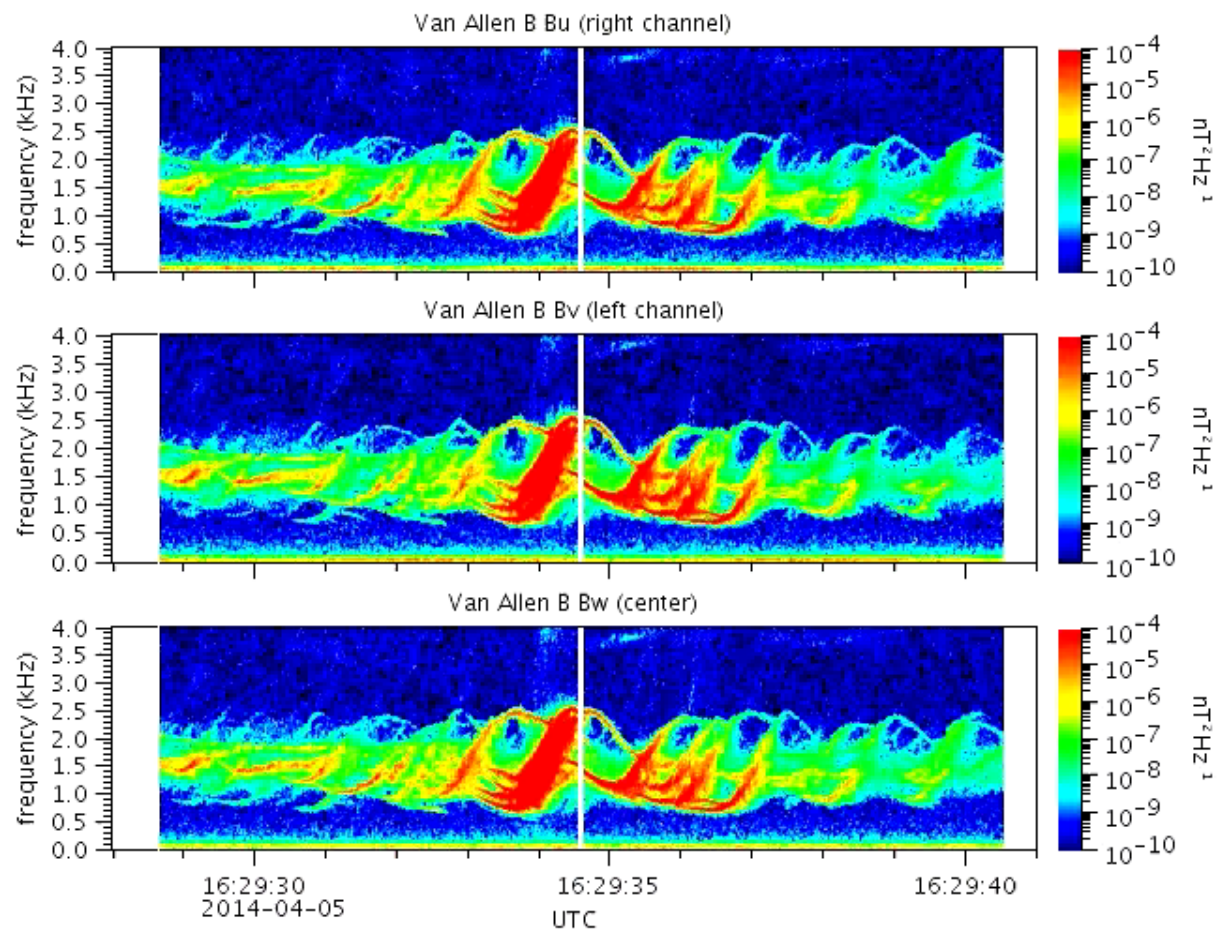




Image U.S. Geological Survey

©2008 Google