

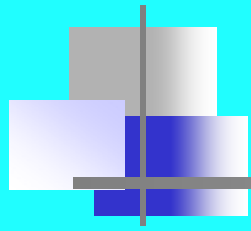
11th Hellenic Astronomical Conference

**Energetic particles
and waves
in geospace: Physics
and space weather effects**

Ioannis A. Daglis

Dept of Physics, University of Athens

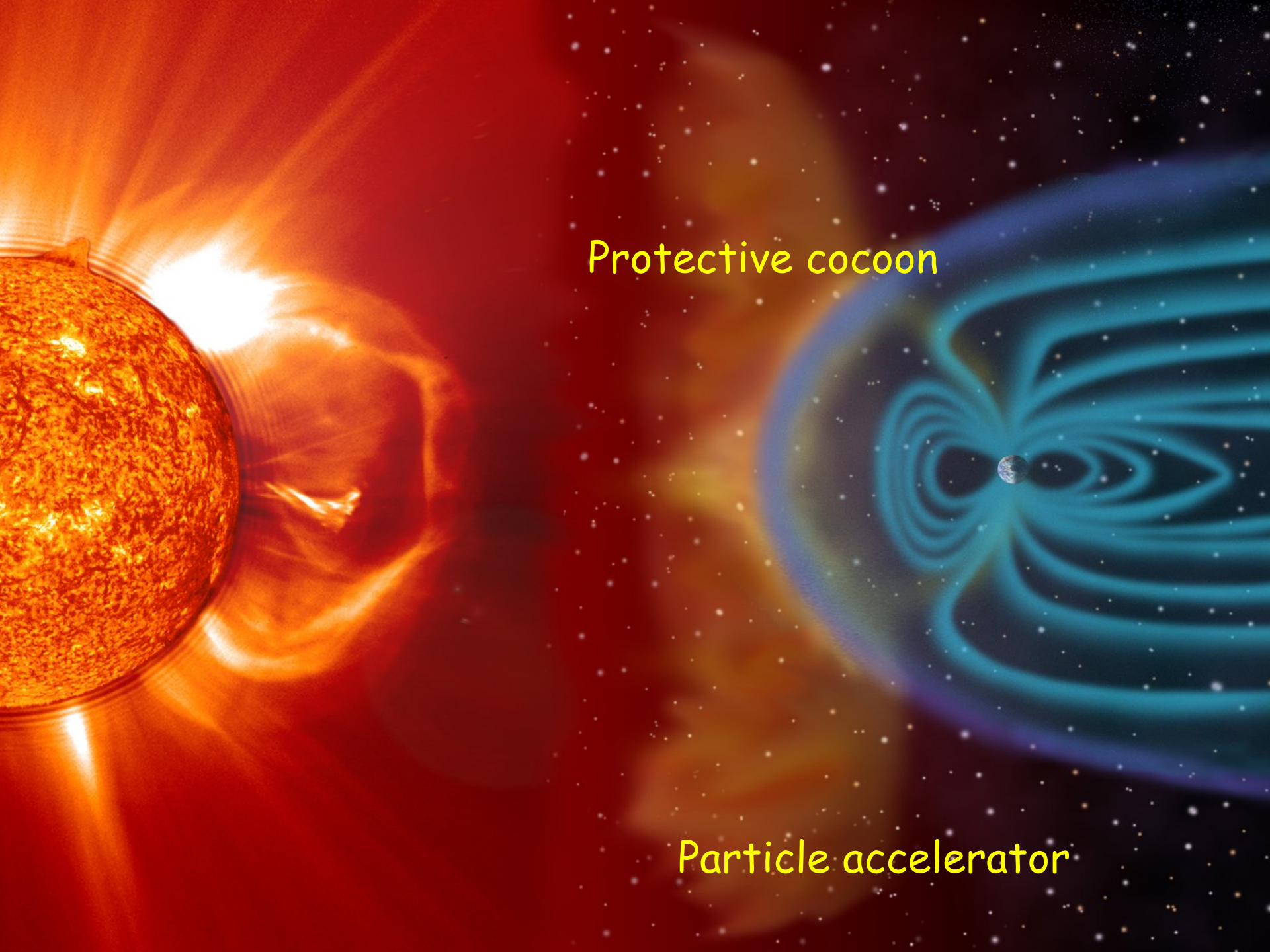




Energetic particles in Geospace

Outline:

- Introductory overview
- Recent paradigm changes
- New insights on storms, waves and particles



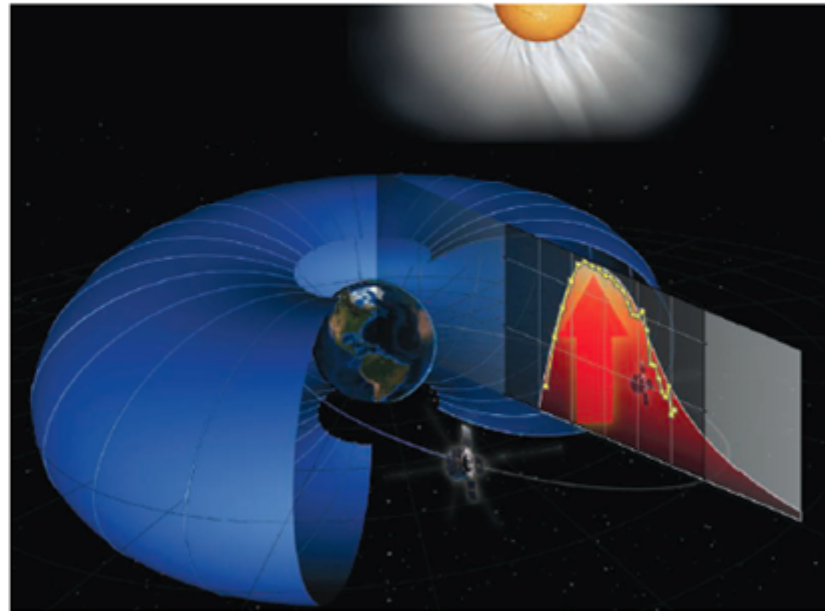
Protective cocoon

Particle accelerator

The Savage Radiation of the Van Allen Belts Is Homegrown

Back in 1958, Explorer 1, the first U.S. satellite, sent back unsettling news: Nearby space was pervaded by radiation intense enough to blind their instruments. The Van Allen radiation belts, extending from about 1000 kilometers to 60,000 kilometers from Earth, have been zapping unlucky satellites—and puzzling space physicists—ever since. Now, at last, researchers have figured out where the electrons that fill the Van Allen belts get their killer energy. A pair of probes launched last year has traced how energy streaming from the sun can boost electrons in the heart of the belts to speeds greater than 99% of the speed of light.

Researchers “have found the key signature” of electrons being accel-

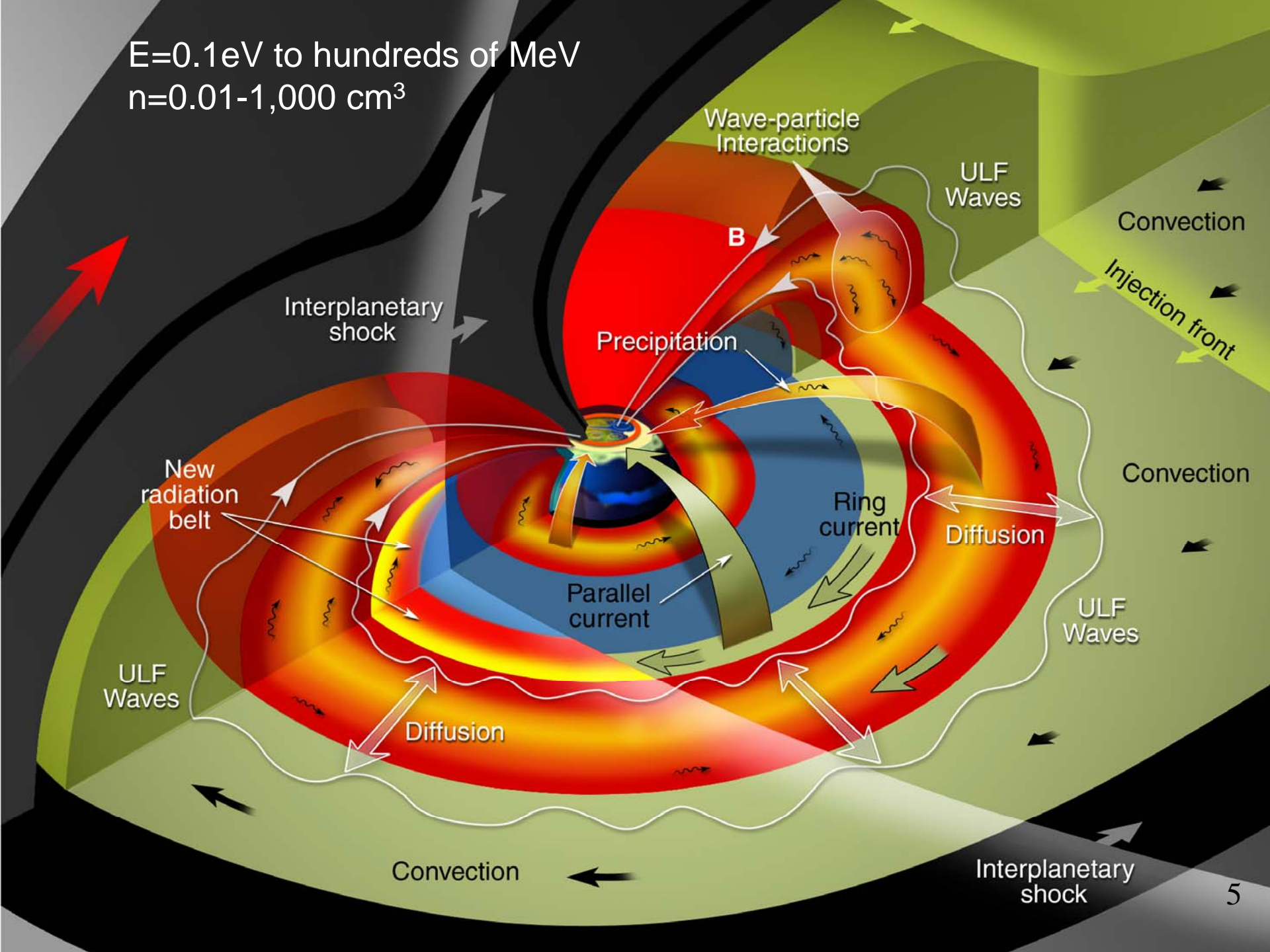


Inner turmoil. Electron energies (yellow curve) detected by two new spacecraft peak inside the radiation belts (including the magnetically defined blue torus) as expected for in situ acceleration (gray curve).

the outer belt, as some theories predicted, the data showed that energy surged among low-energy electrons already in the belts, Reeves says. Powerful electromagnetic waves in the solar wind were almost certainly transferring their energy to the resident electrons, boosting them to speeds at which they can fry a satellite's electronics.

It's still unclear which of a half dozen kinds of waves is the primary driver. But the most likely energy source, Reeves says, is so-called chorus waves, so named because, when converted to sound, their natural frequencies resemble a dawn chorus of birds. Chorus waves that are in sync with electrons spiraling about magnetic field lines would

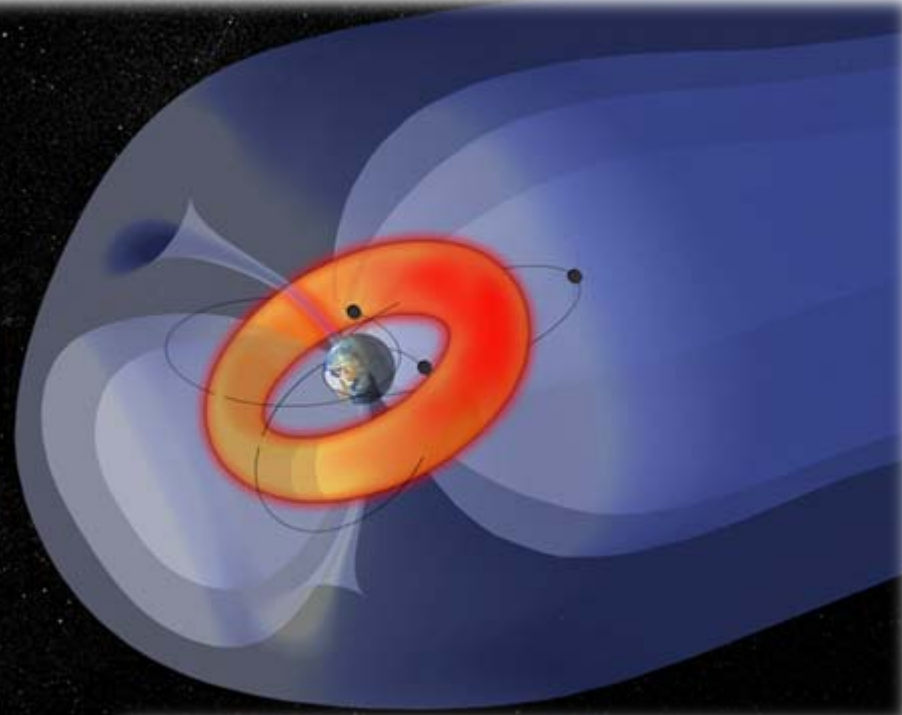
$E=0.1\text{eV}$ to hundreds of MeV
 $n=0.01\text{-}1,000\text{ cm}^3$



RB:

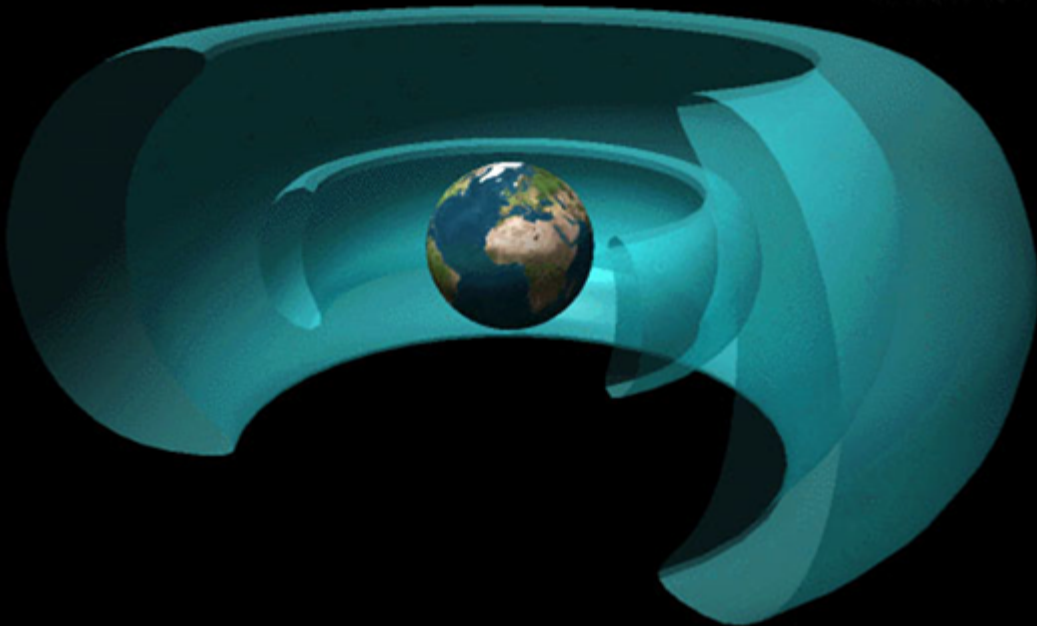
Trapped electrons: 10s keV to ~MeV

Trapped protons: 0.1 to 100s MeV



RC:

Trapped ions 10s to 100s keV

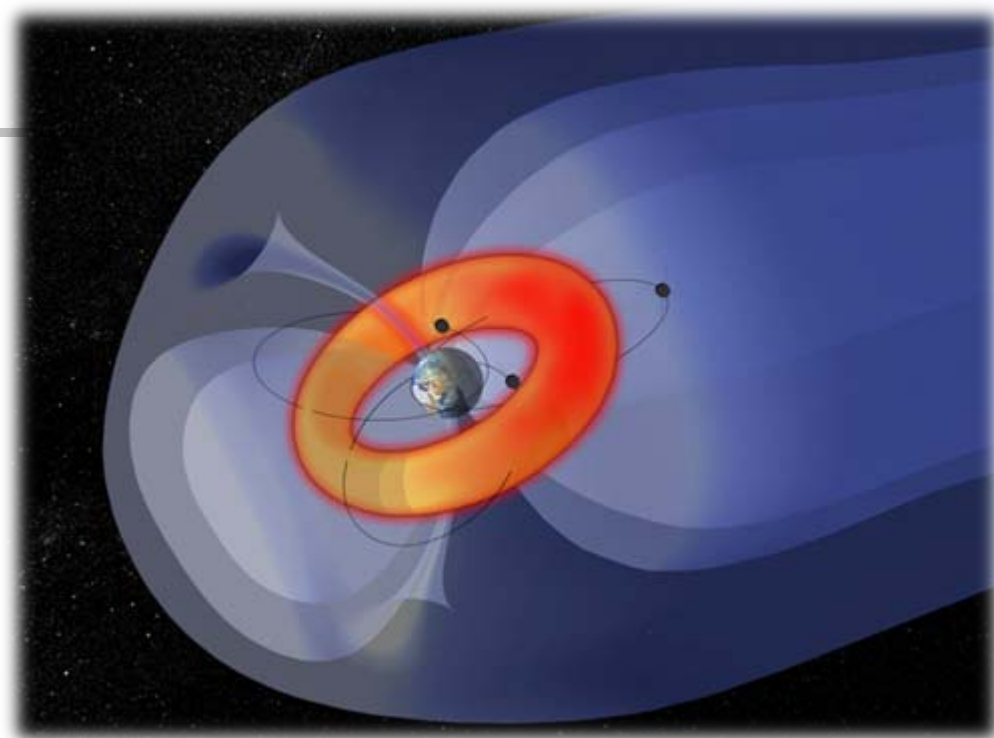


Ring current

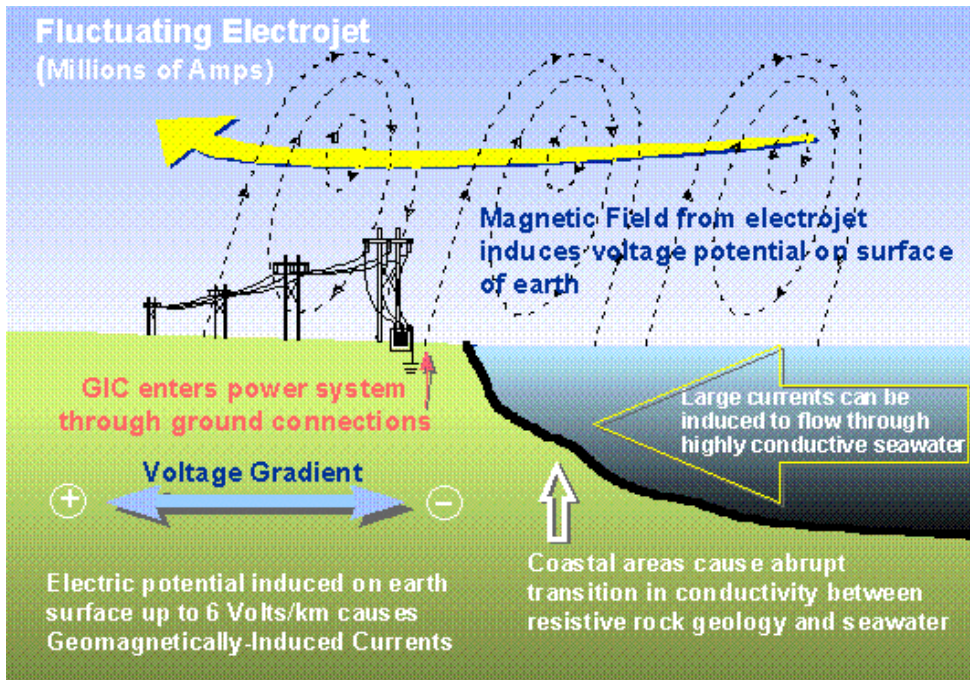
- Electric current (\sim MA) encircling the Earth
- Carried by energetic ions (10s-100s keV)
- Responsible for global ΔB

Main issues: Growth and decay mechanisms, relation with waves and RB dynamics

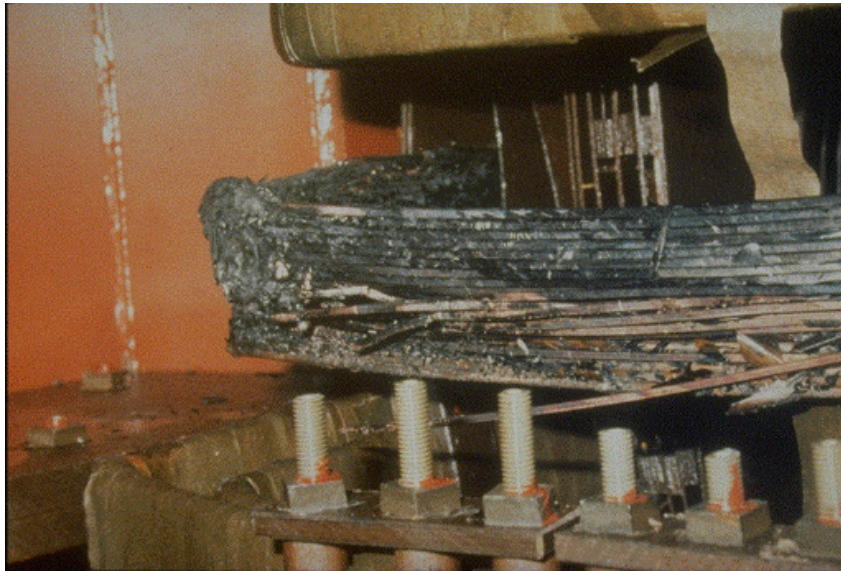
SW effects: Geomagnetically-Induced Currents (power grids, oil pipelines)



Geomagnetically-Induced Currents



- power grids,
- oil and gas pipelines (increased corrosion)
- train light signals can be affected (two documented events in Sweden)



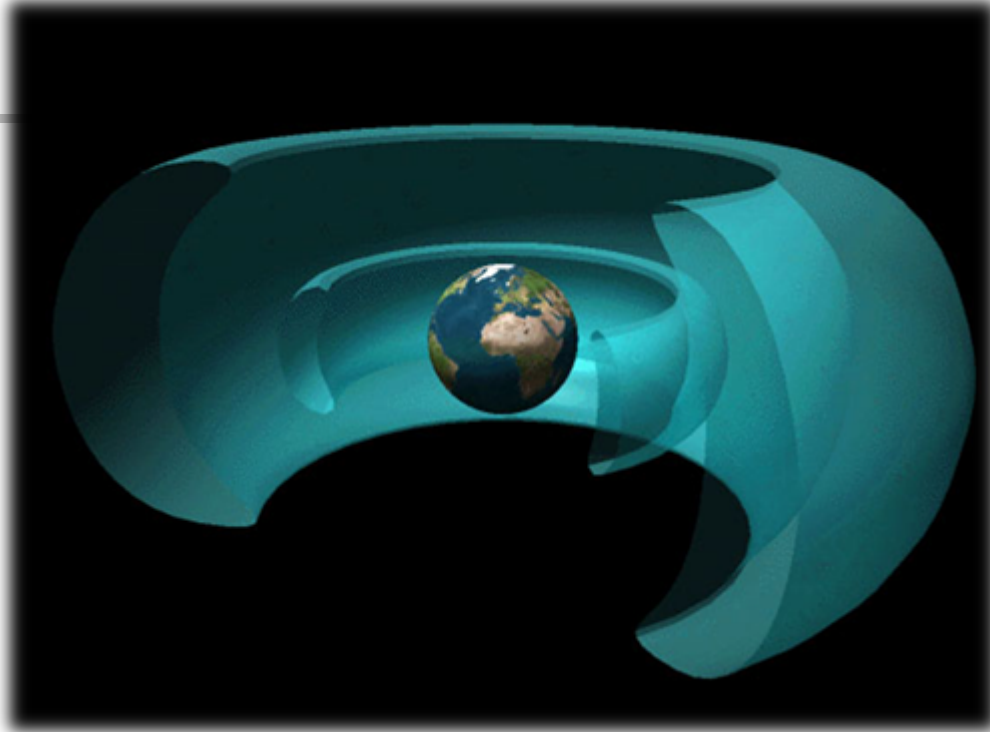
Damage to a transformer at a power plant in Delaware, New Jersey in March 1989 (10 M\$)

Radiation belts

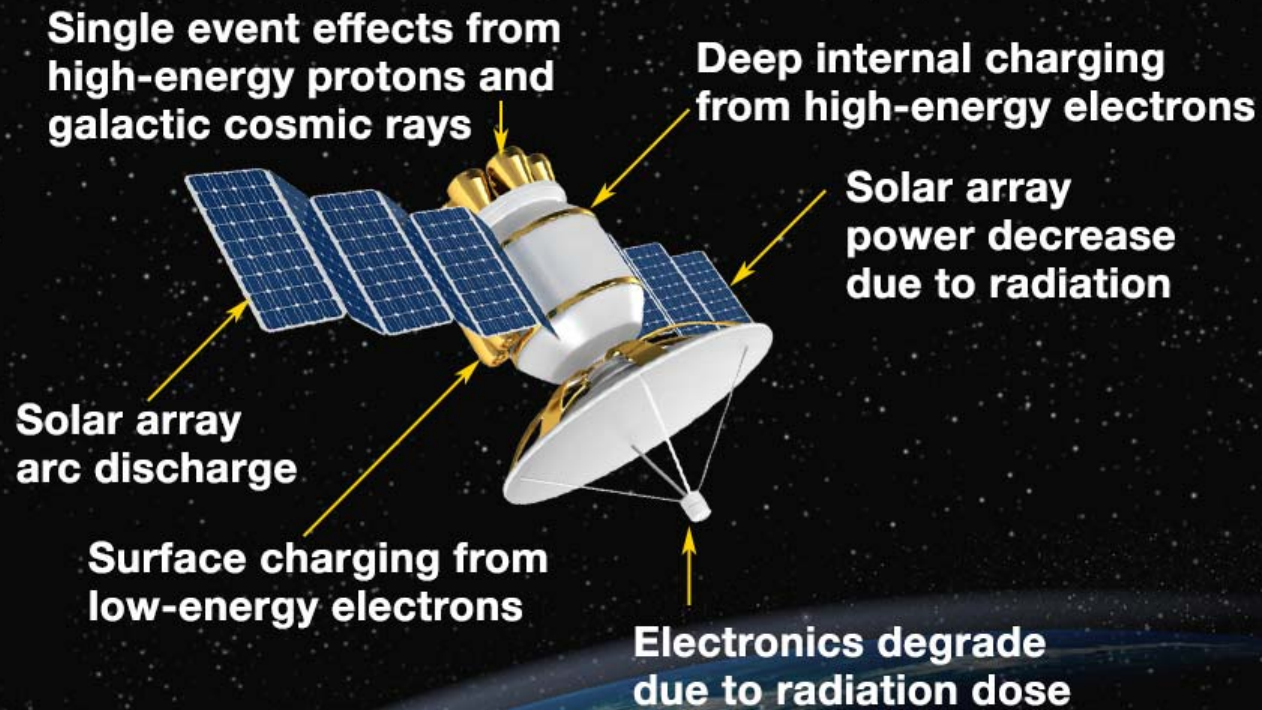
- Toroidal-shaped high-energy, magnetically confined plasma
- Protons (up to hundreds of MeV) and electrons (up to several MeV)

Main issues: Growth and decay mechanisms

SW effects: Spacecraft anomalies,
radio propagation disturbances



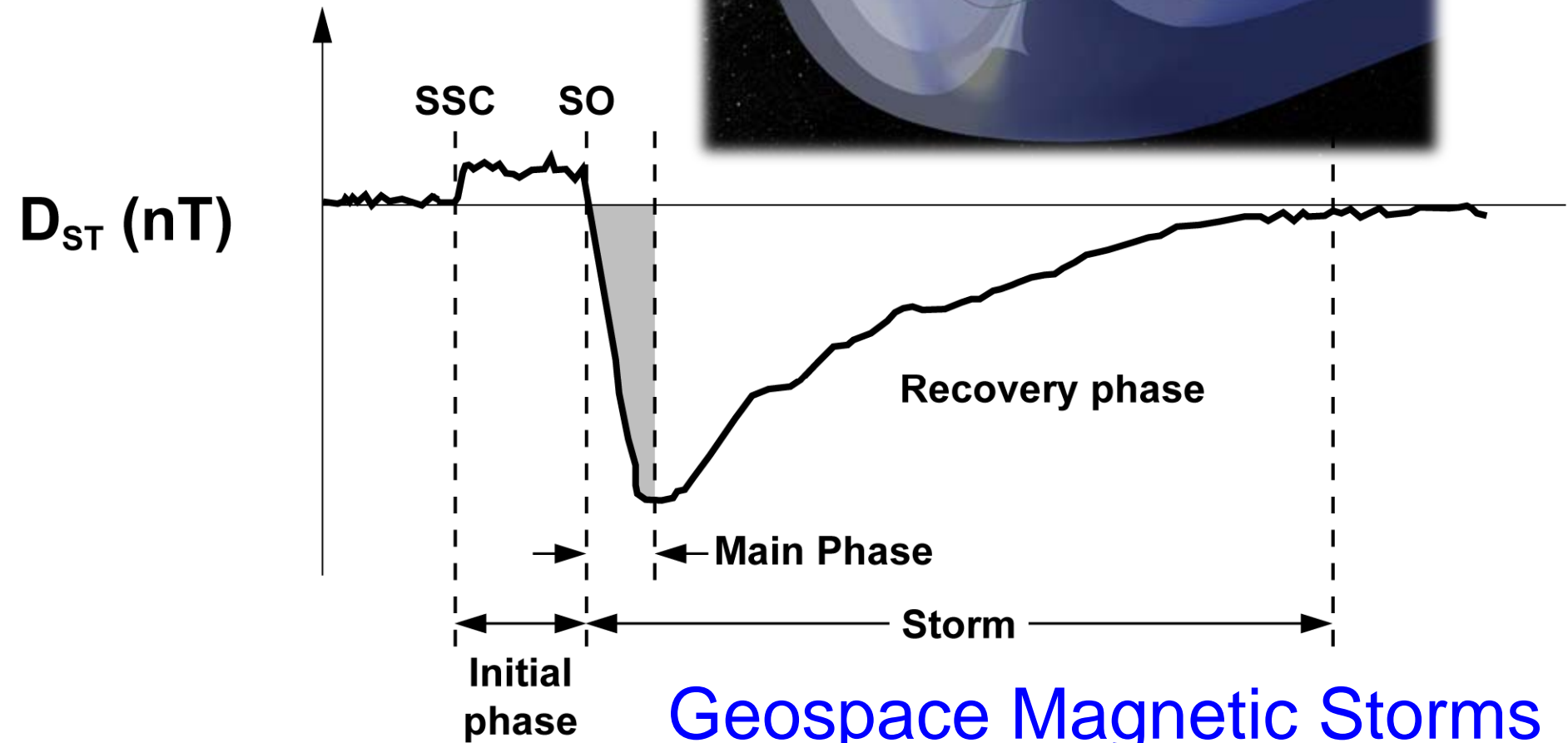
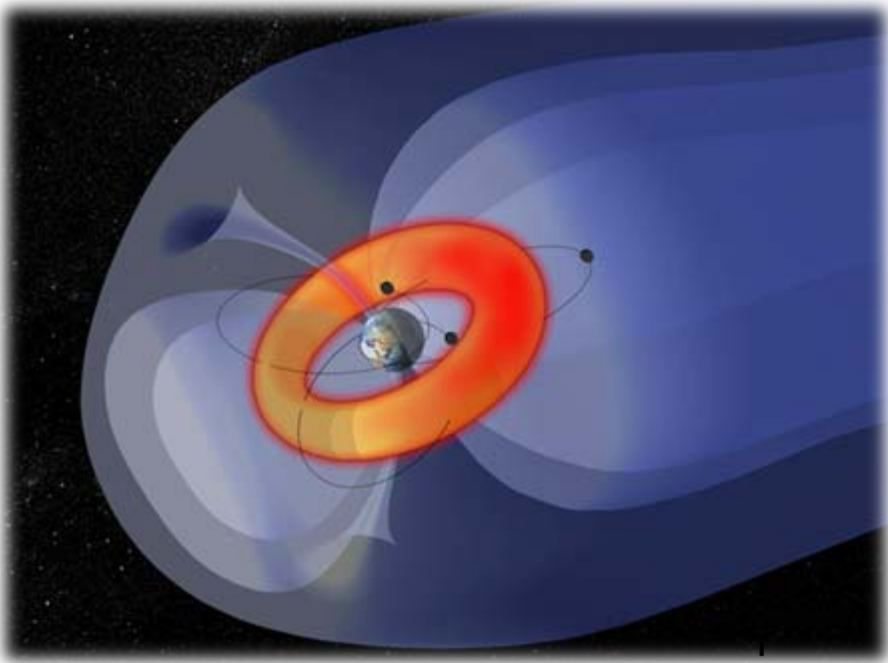
Space Environment Hazards



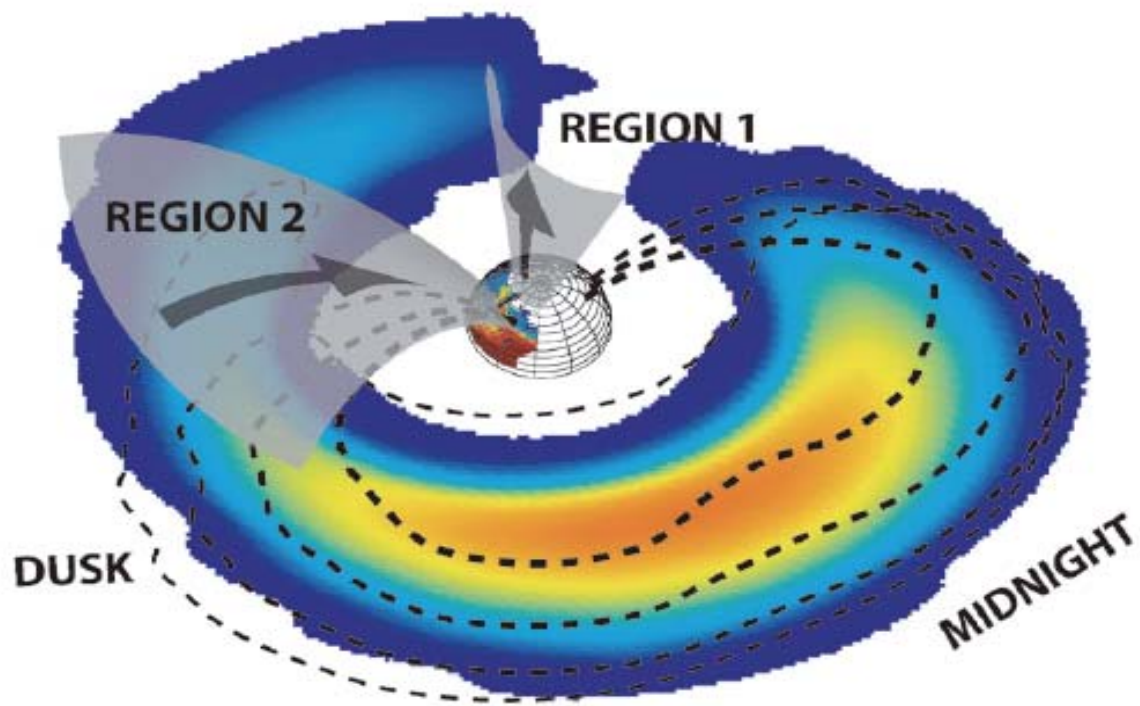


Ring Current

Paradigm Changes

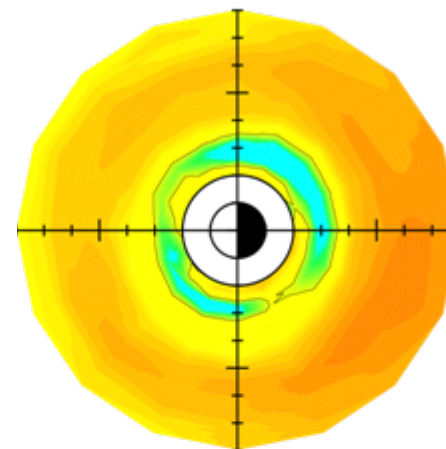


Geospace Magnetic Storms

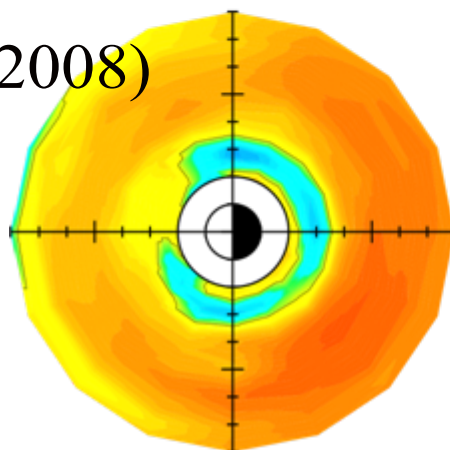


Current Intensity
1.6 R_E

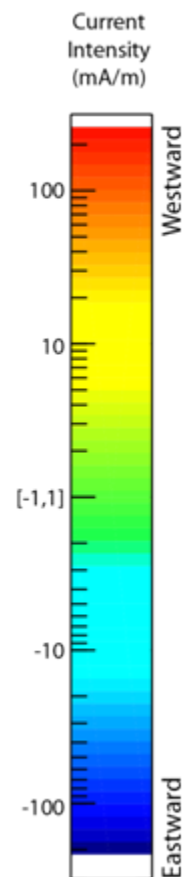
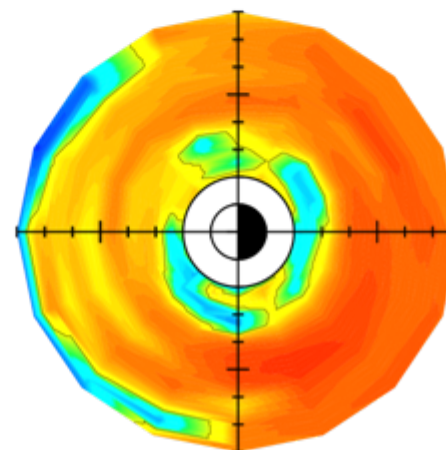
(b) $-40 \text{ nT} > \text{Dst}^* > -60 \text{ nT}$



(c) $-60 \text{ nT} > \text{Dst}^* > -80 \text{ nT}$

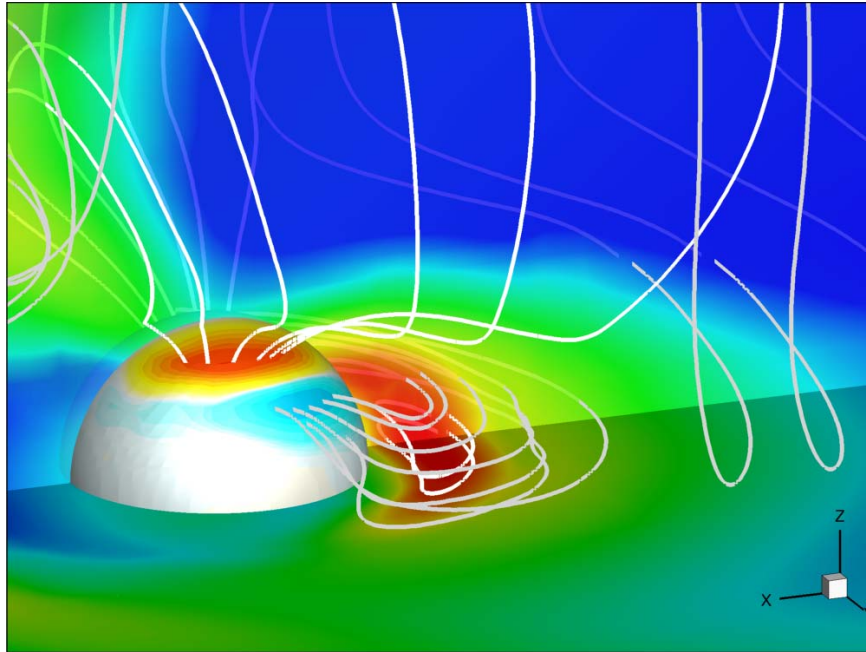


(d) $-80 \text{ nT} > \text{Dst}^* > -100 \text{ nT}$



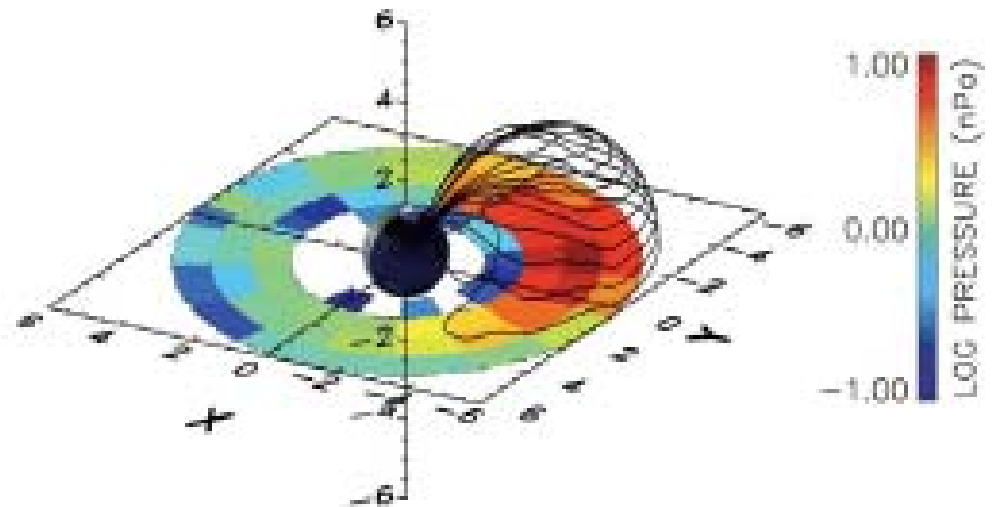
Brandt et al. (2008)

Other currents: the Banana current

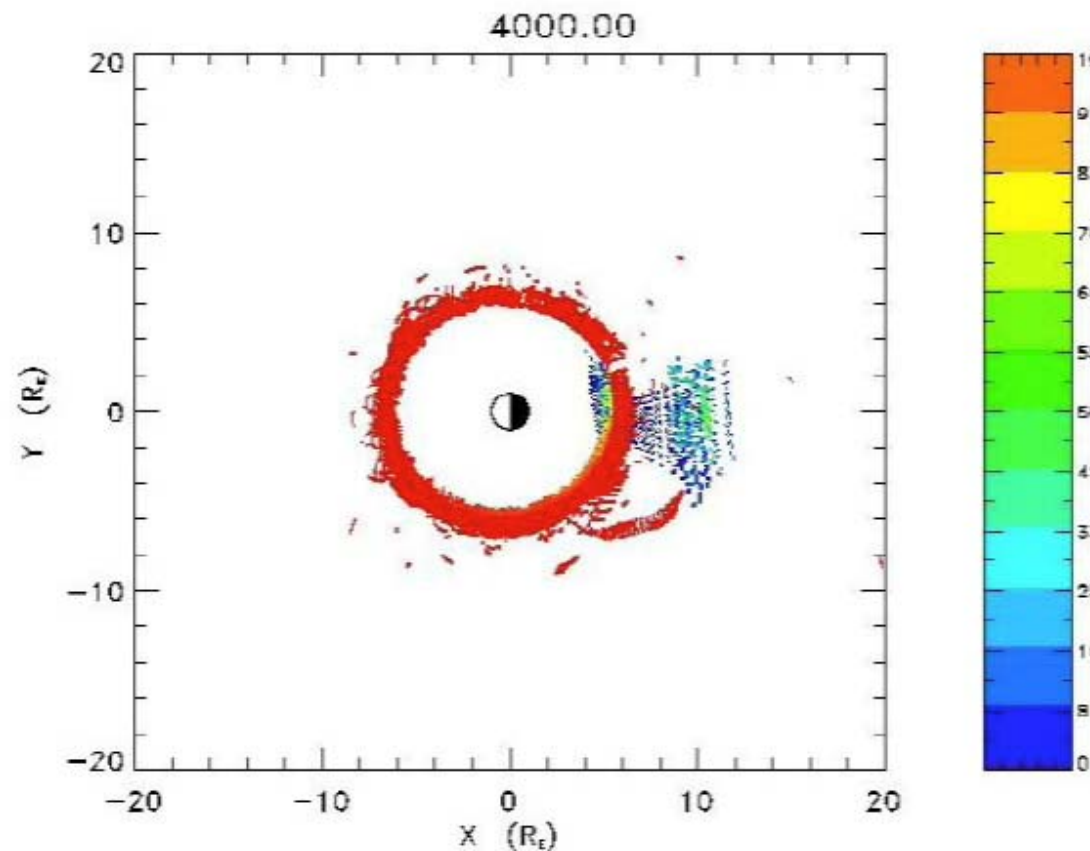
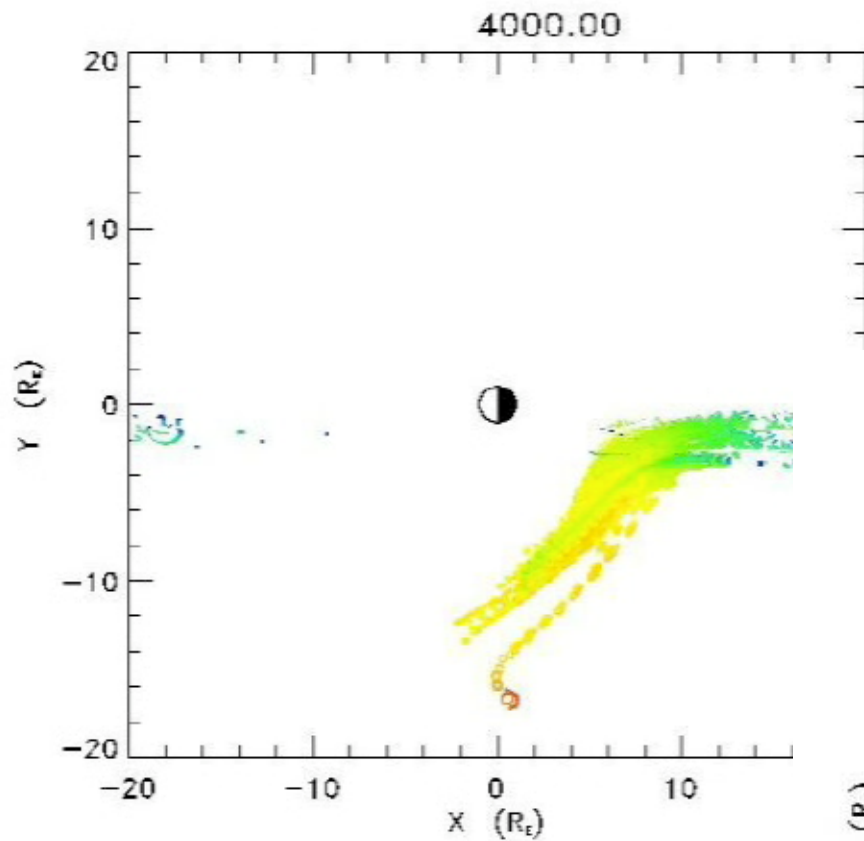


Models

Data (IMAGE/HENA)



Solar/ionospheric source, Convection/substorms



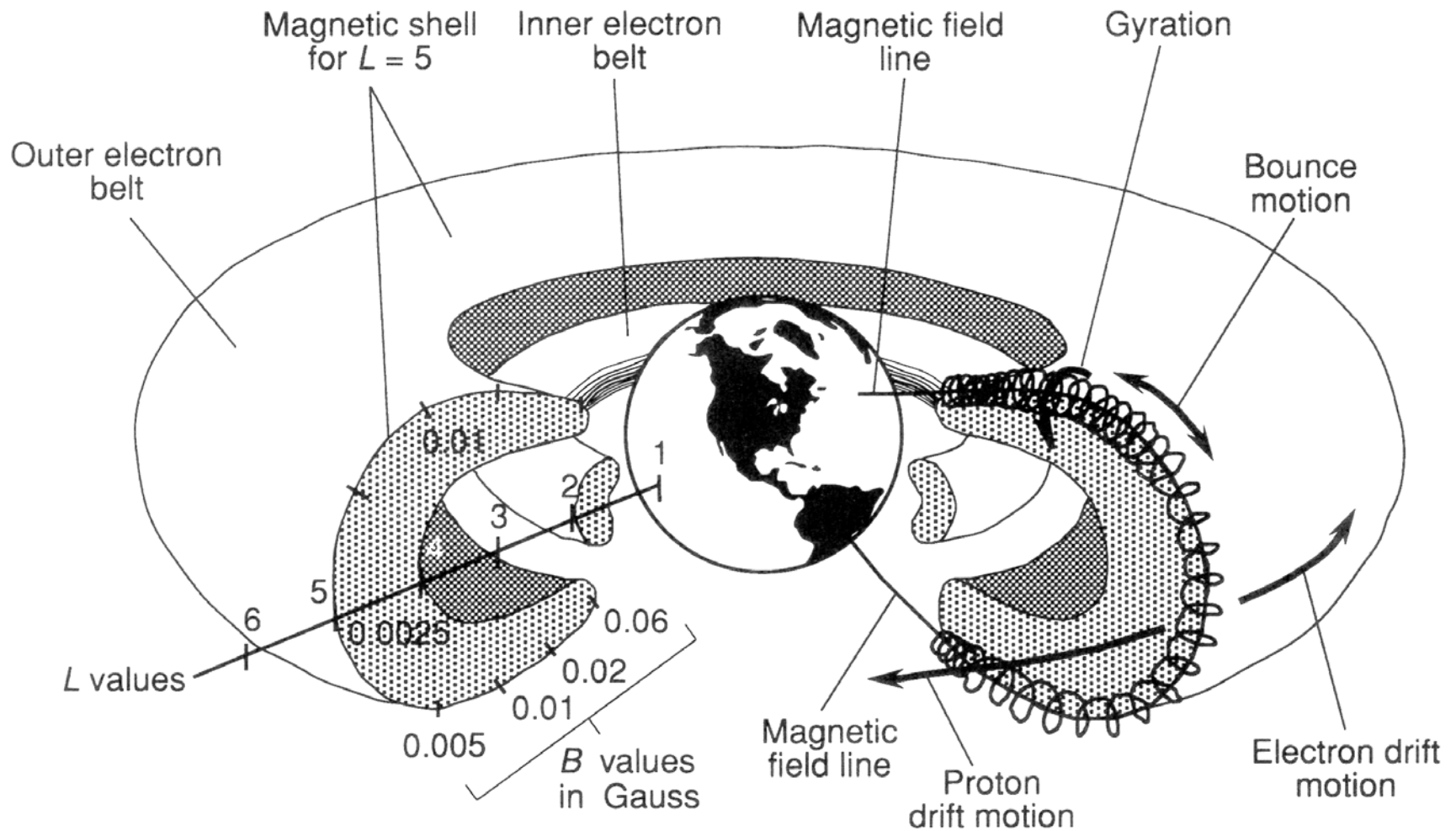
Metallinou, 2006



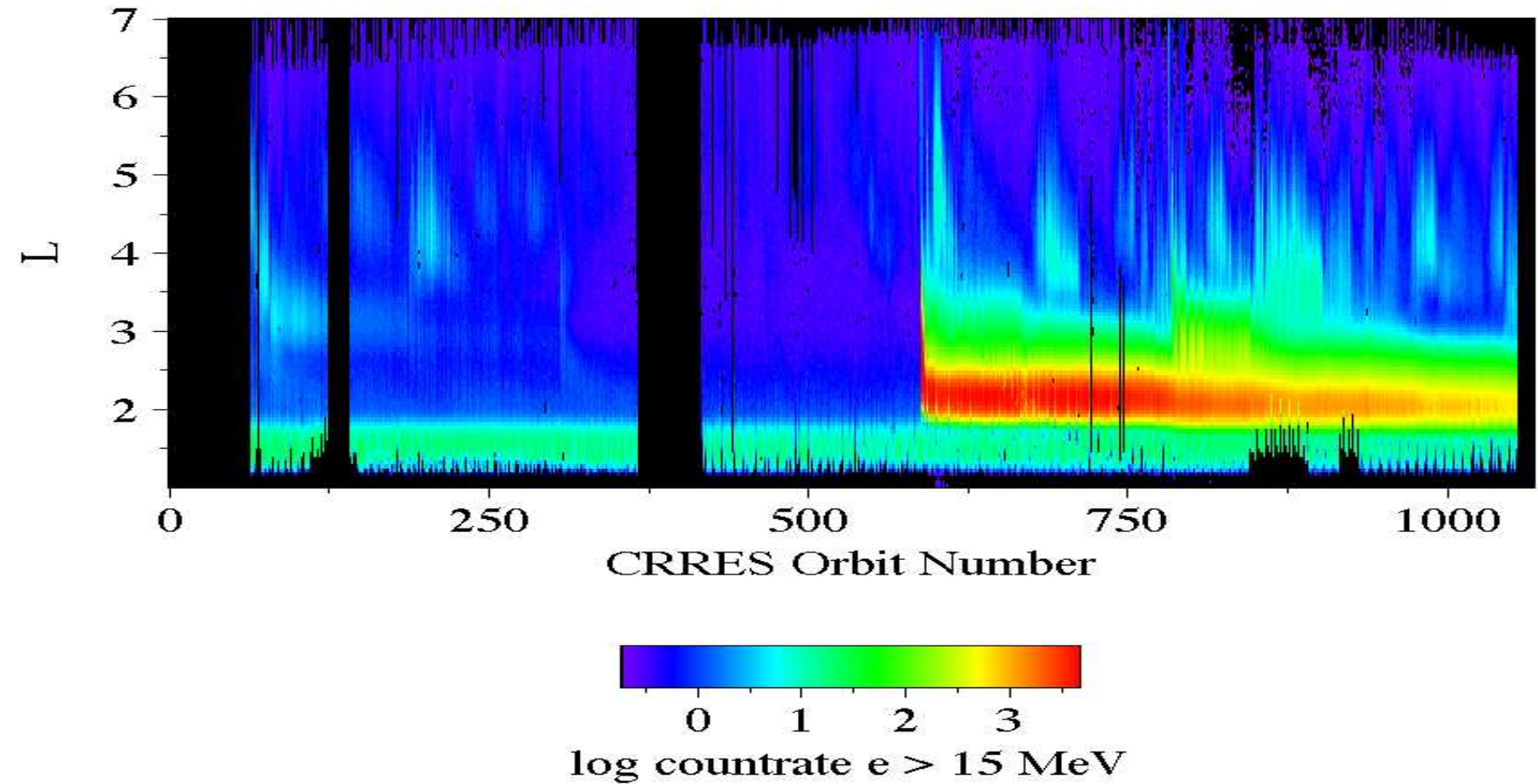
Radiation Belts

Paradigm Changes

Radiation belts



Radiation Belts - the Slot region

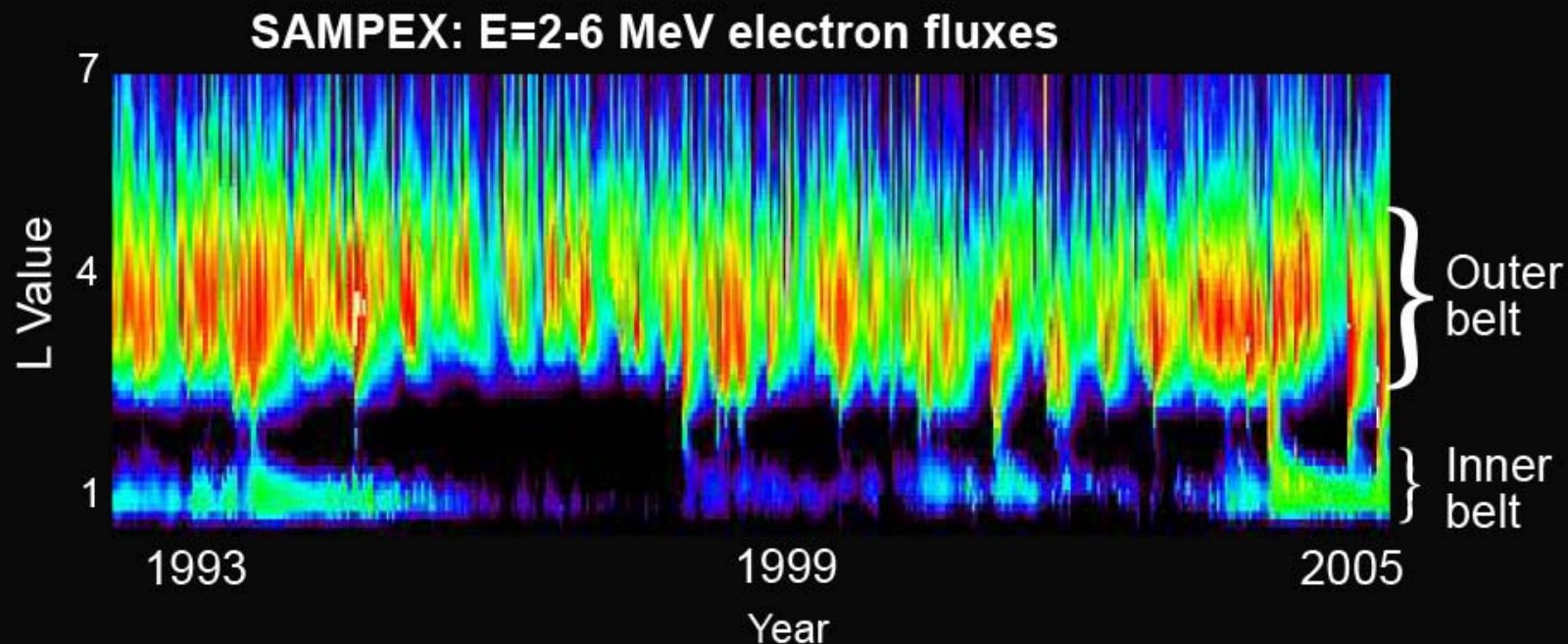


(CRRES, Bernie Blake)

Radiation Belts - the two-belts structure

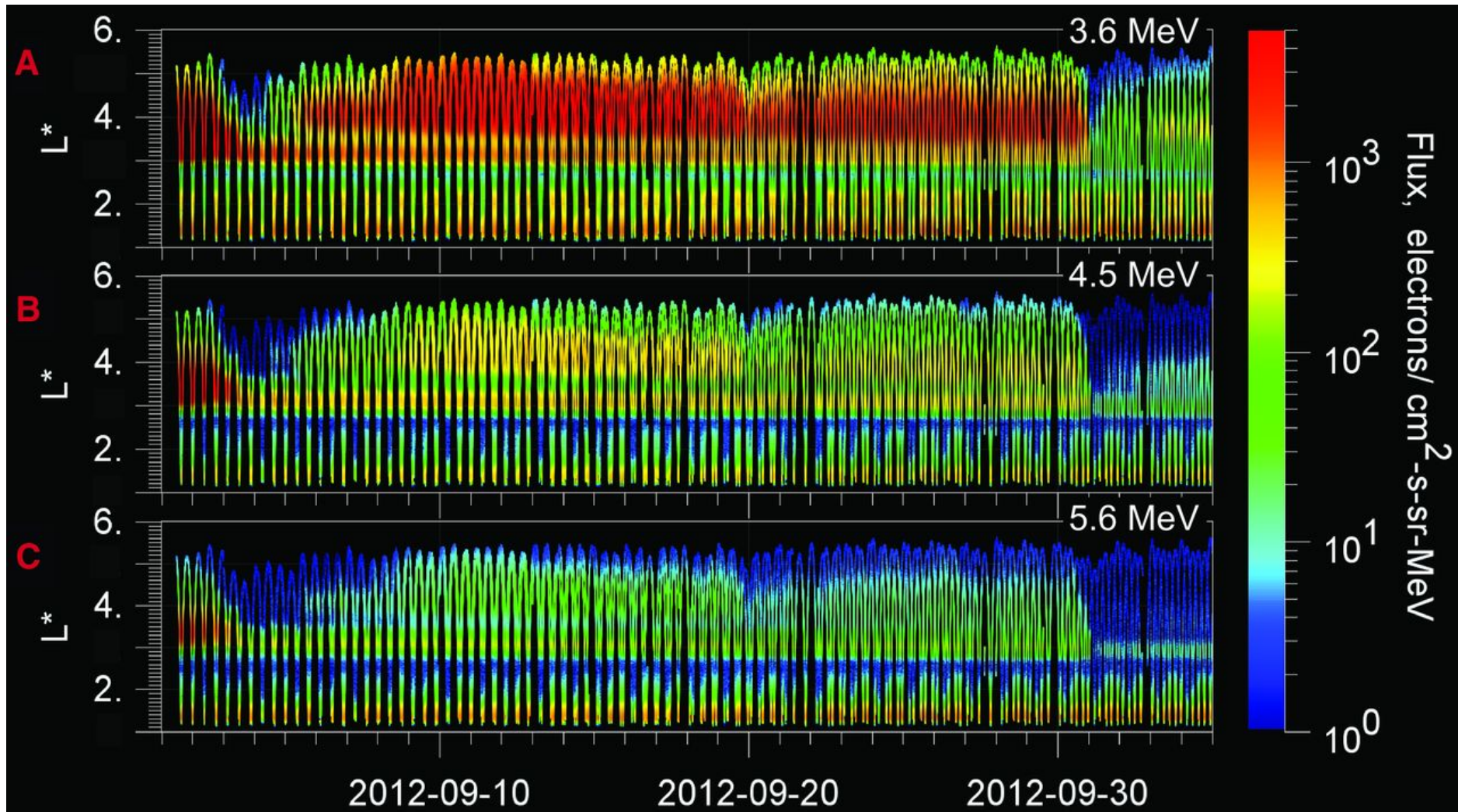
SAMPEX Shows Traditional Two Belt Structure

Long term (~12 year) plot from SAMPEX shows the established two belt structure

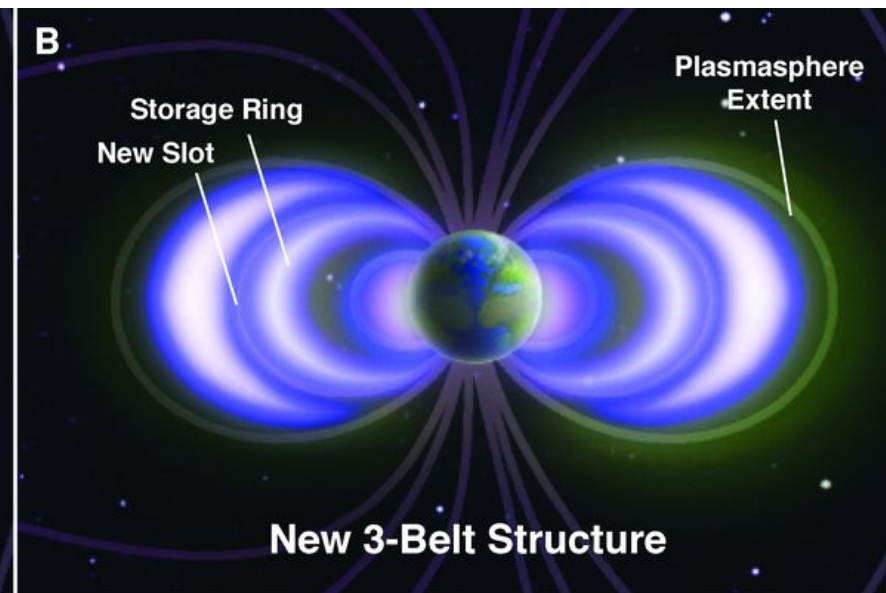
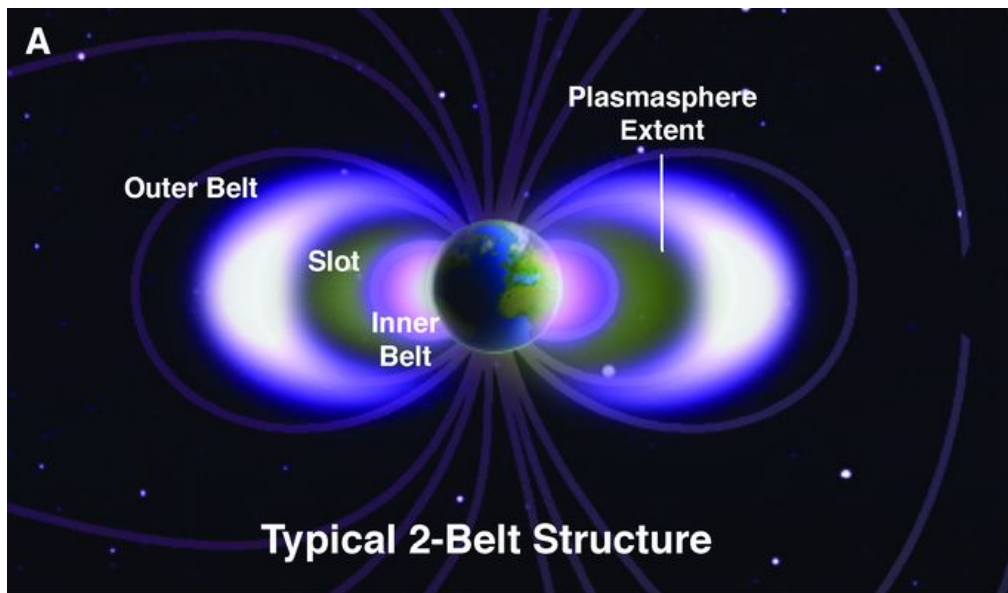
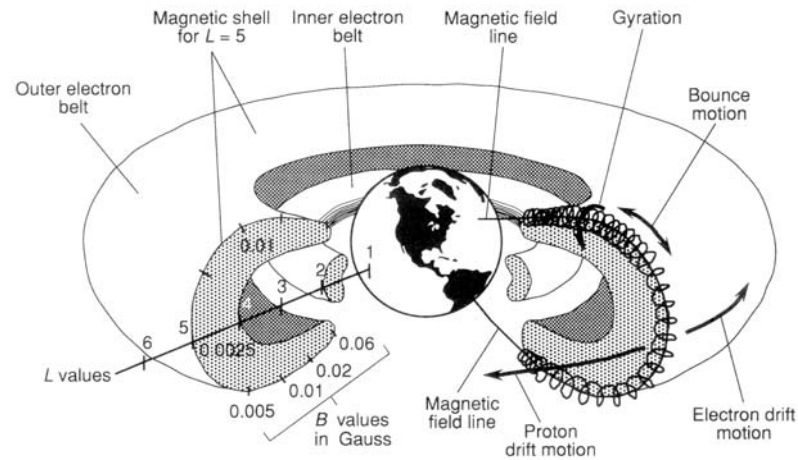


Radiation Belts - the two-belts structure

Relativistic Electron Probe Telescope data from the RBSP satellites



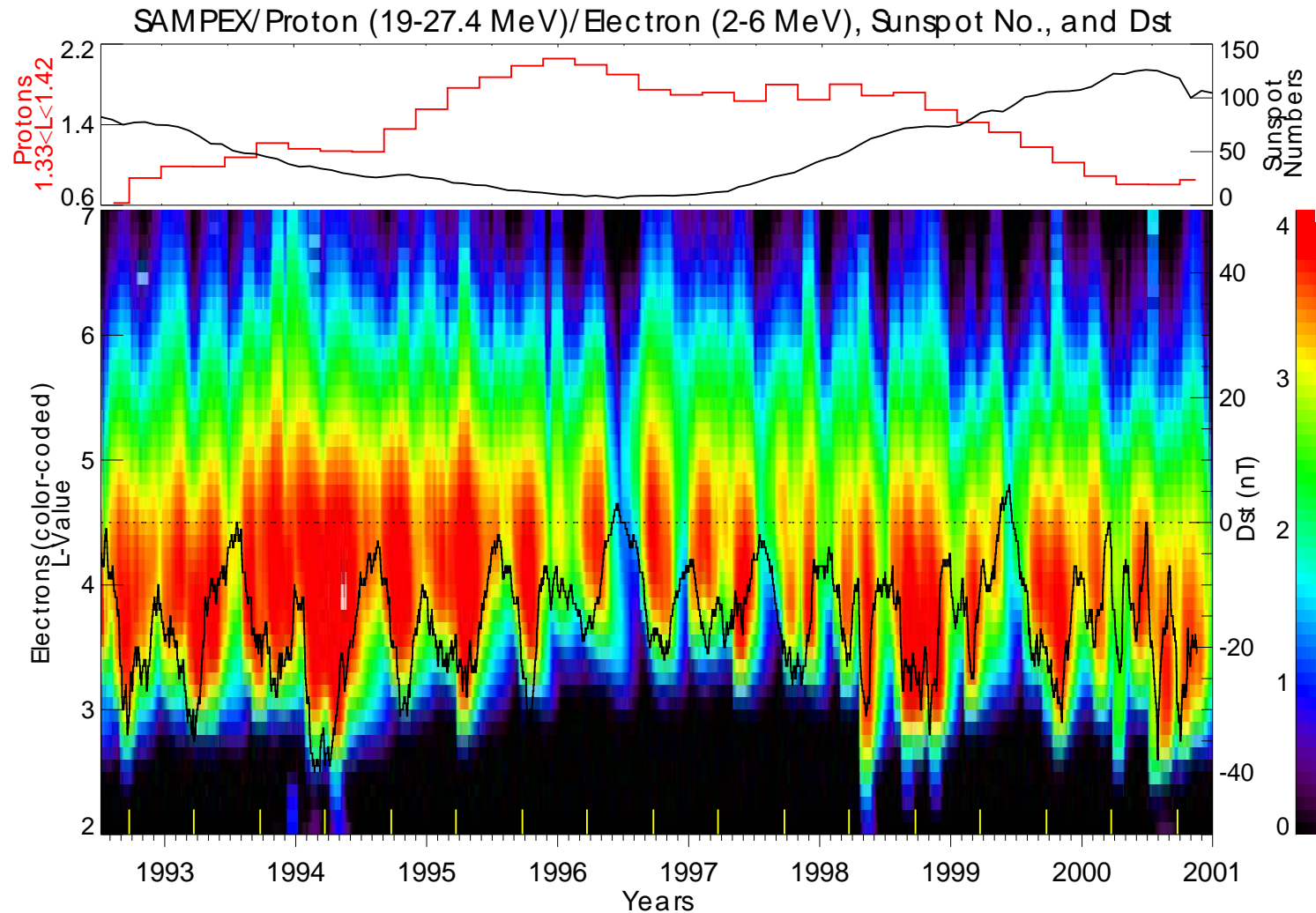
Radiation Belts - the two-belts structure





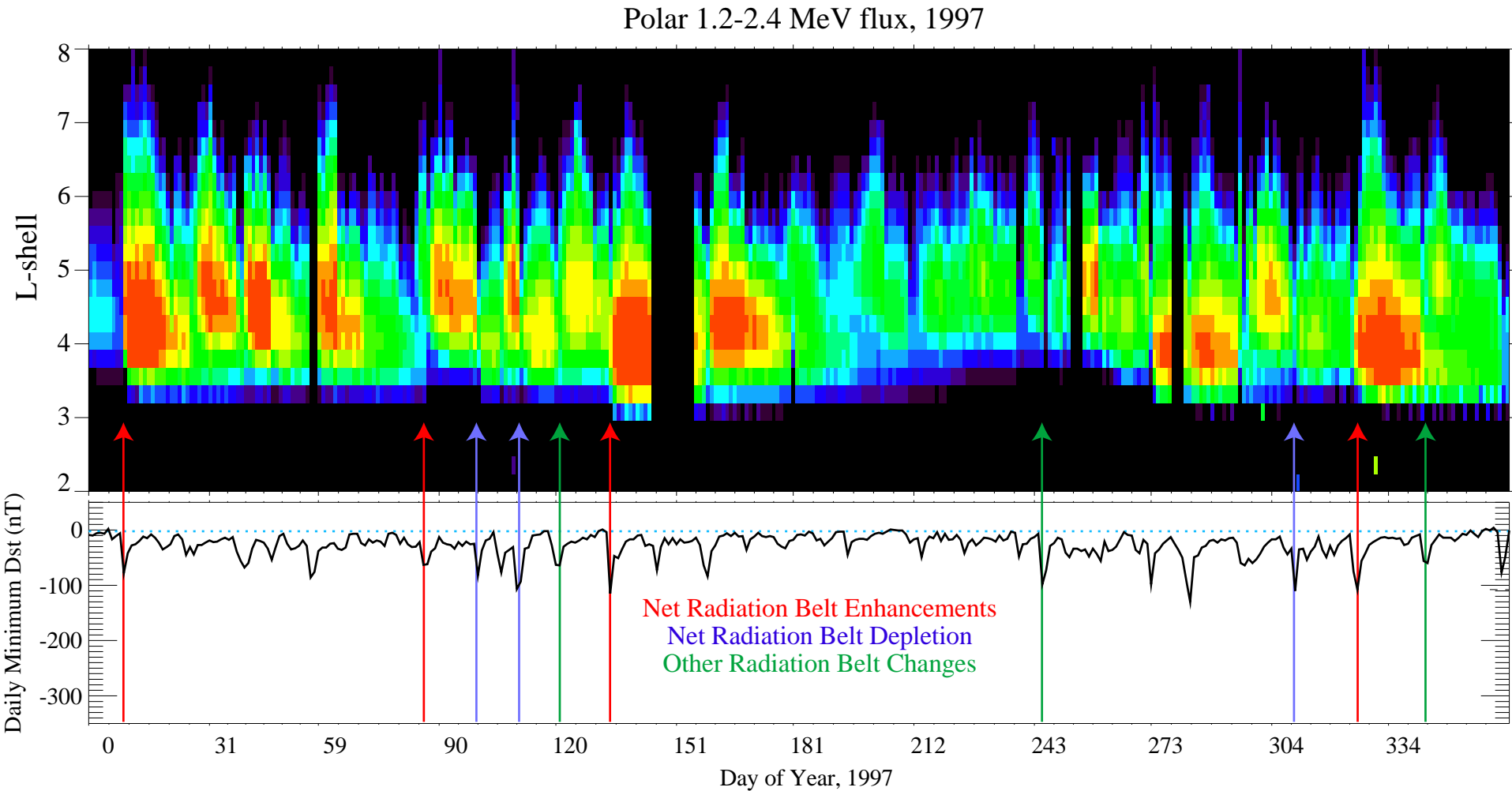
Magnetic Storms and Radiation Belts

Magnetic Storms and Radiation Belts

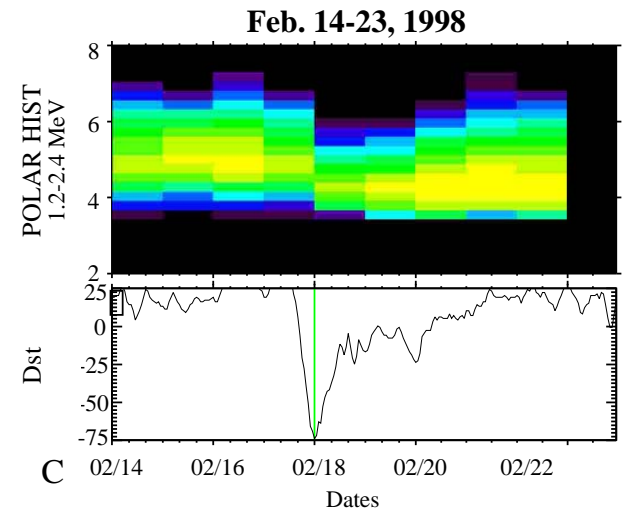
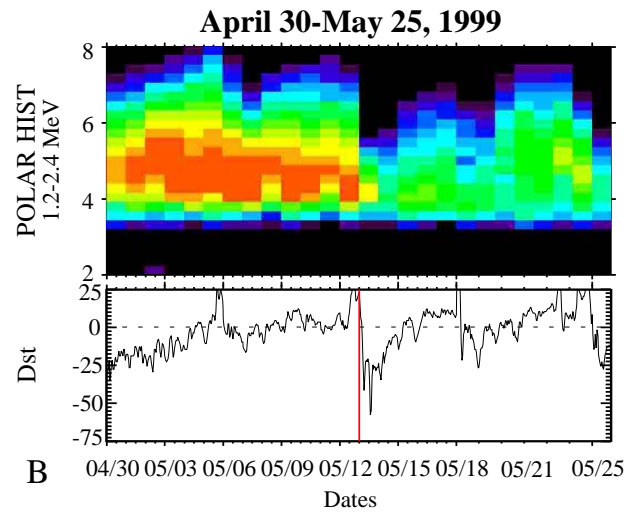
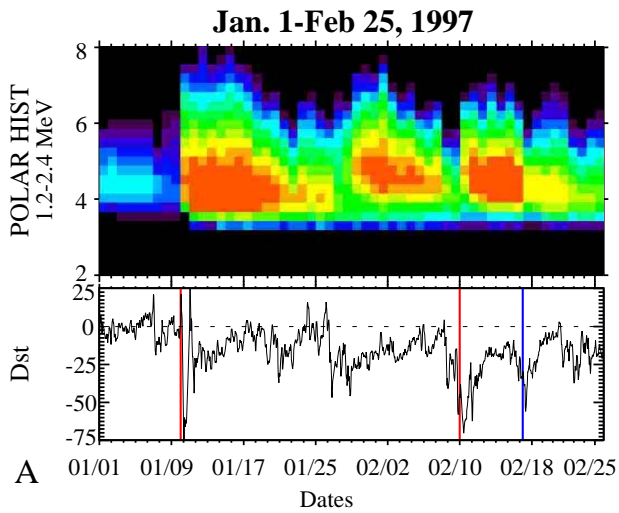


Close correlation with storms / Large dynamic range: 10 to 10^4

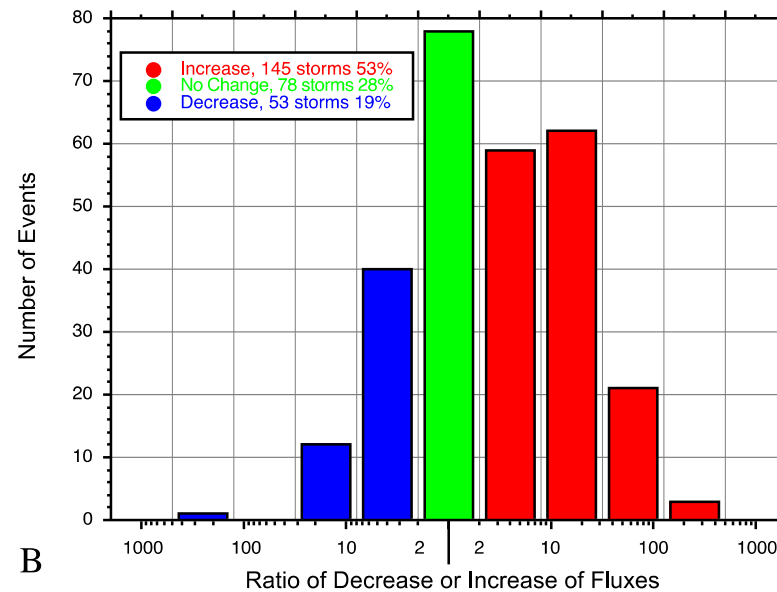
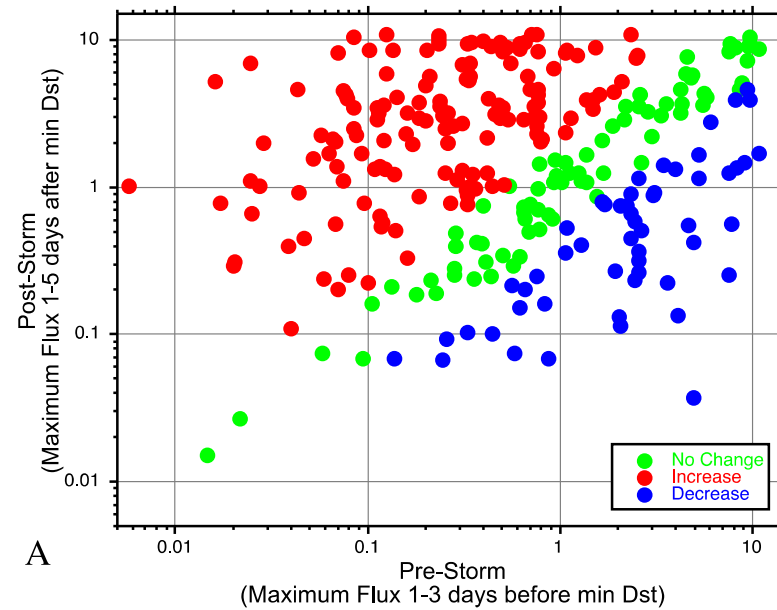
Magnetic Storms and Radiation Belts




Magnetic Storms and Radiation Belts



Magnetic Storms and Radiation Belts



1989-2000 Geosynch
Reeves et al., GRL2003



Is there a connection
between
the Radiation Belts
and magnetic storms
(i.e. the Ring Current) ?



The diagram illustrates the Earth's magnetosphere. At the top left, a bright sun emits rays. The Earth is shown in the center-right, with a satellite orbiting it. The magnetosphere is depicted as a series of concentric, swirling bands of color (red, yellow, green, blue) representing different regions. Three callout circles are connected to the magnetosphere by red lines: an orange circle labeled '1 Van Allen Belts' points to the innermost region; a blue circle labeled '2 Ring Current' points to the middle region; and a green circle labeled '3 and their wave coupling' points to the outermost region.

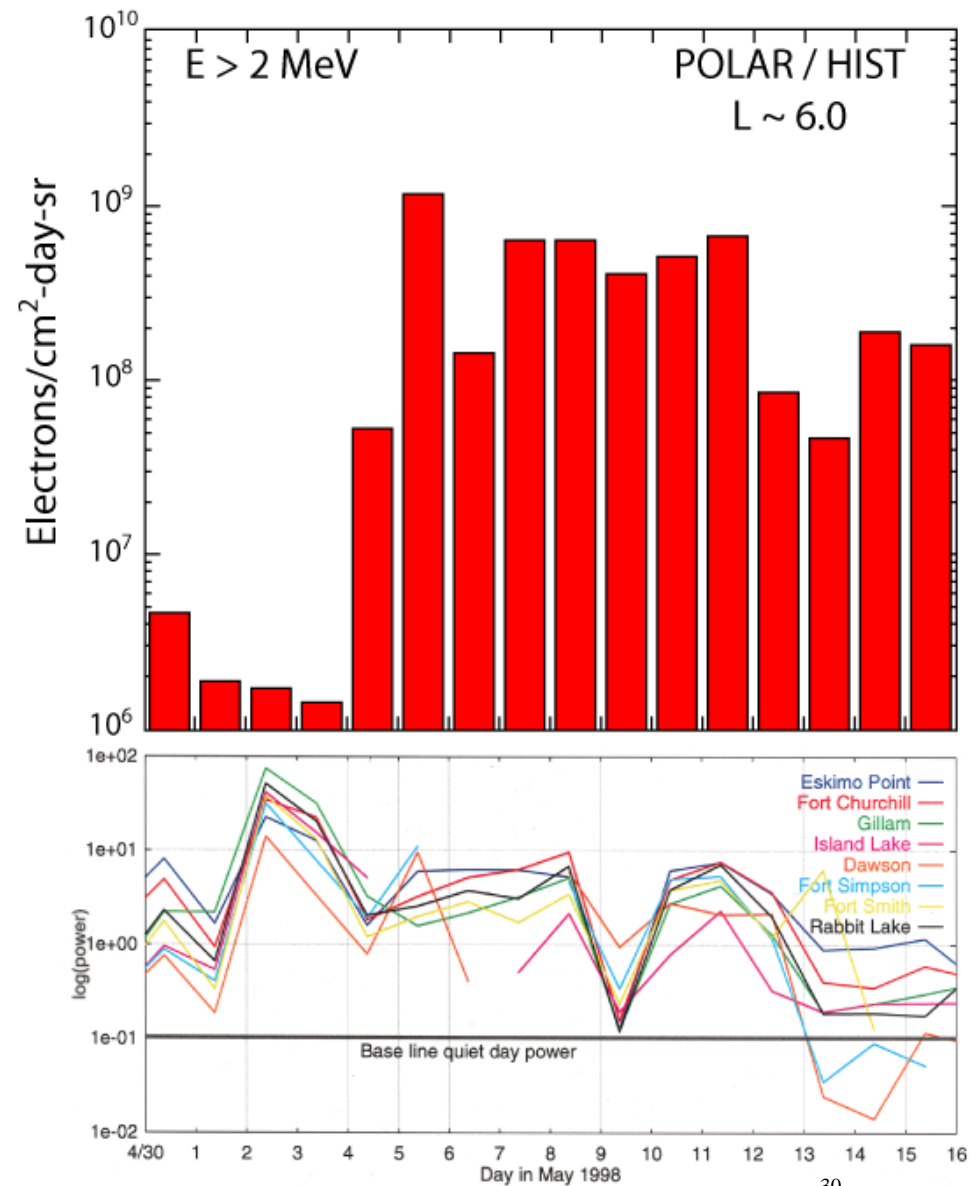
1
**Van Allen
Belts**

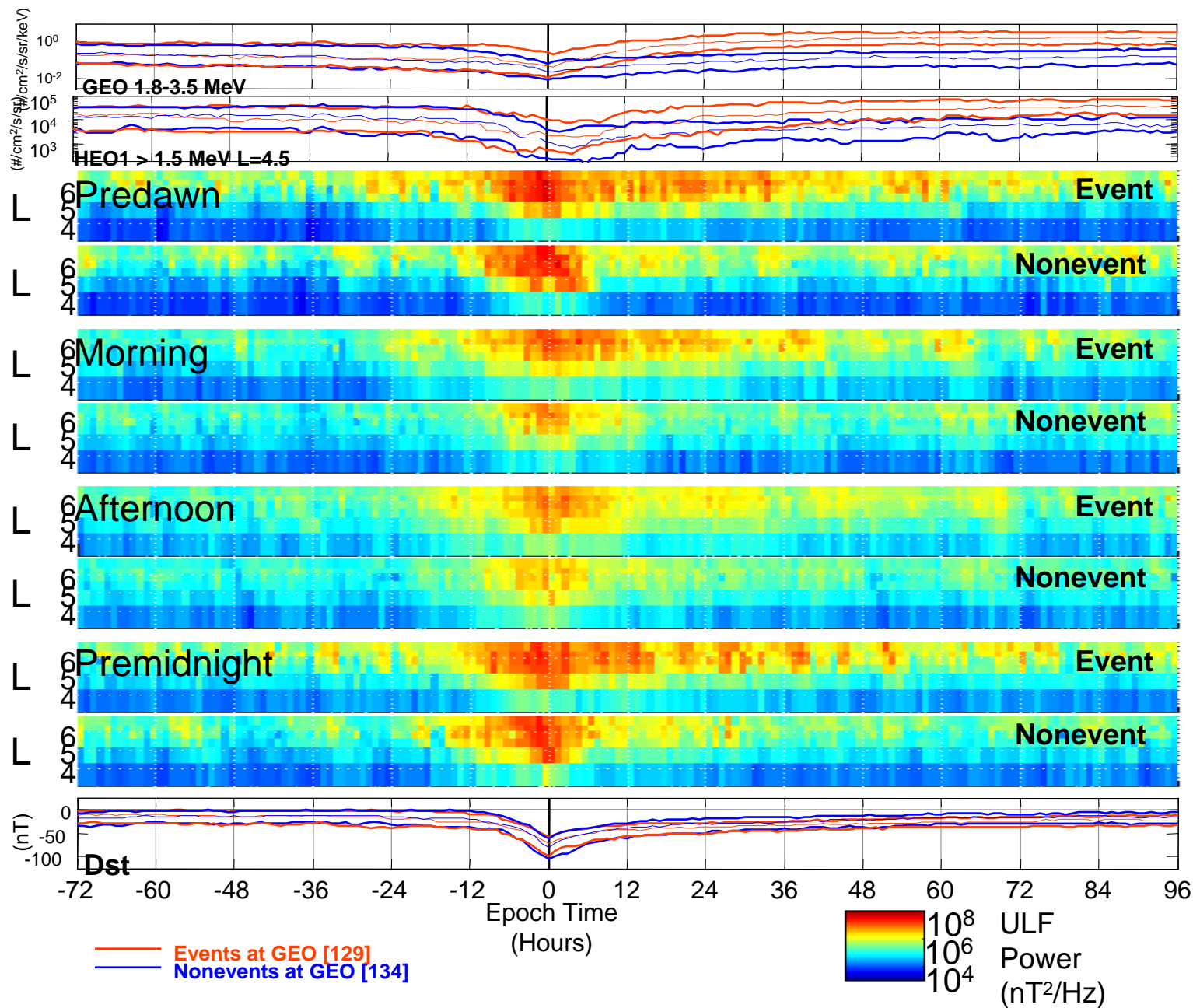
2
**Ring
Current**

3
**and their
wave
coupling**

ULF Waves and Radiation Belts

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





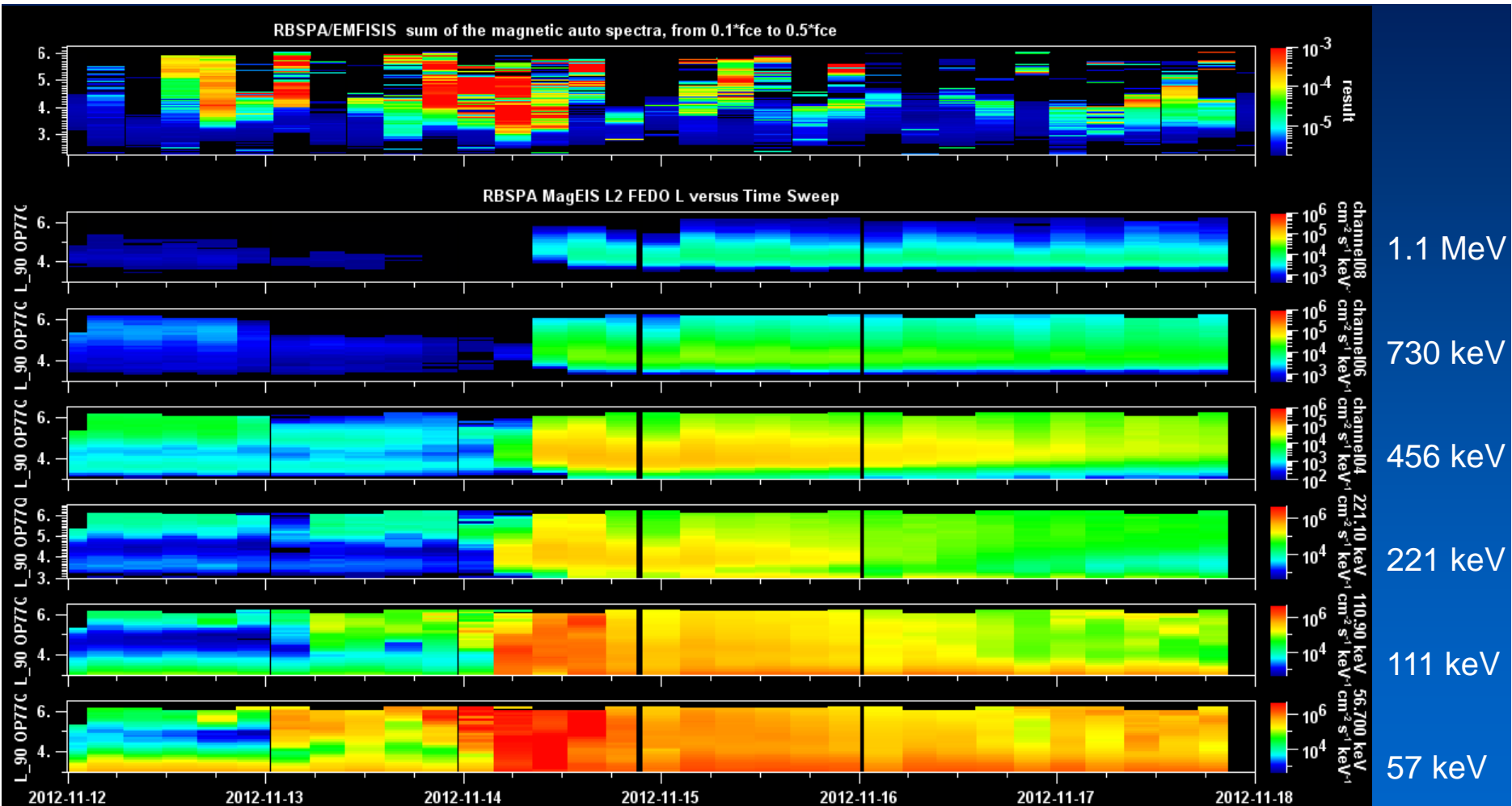
Storm-time waves have also been connected to
RB losses

=> through pitch-angle scattering
by EMIC waves (Pc1-2) into the loss cone
and subsequent loss into the atmosphere

=> through radial diffusion
by ULF waves (Pc3-5)
and subsequent outward transport and loss at the
magnetopause

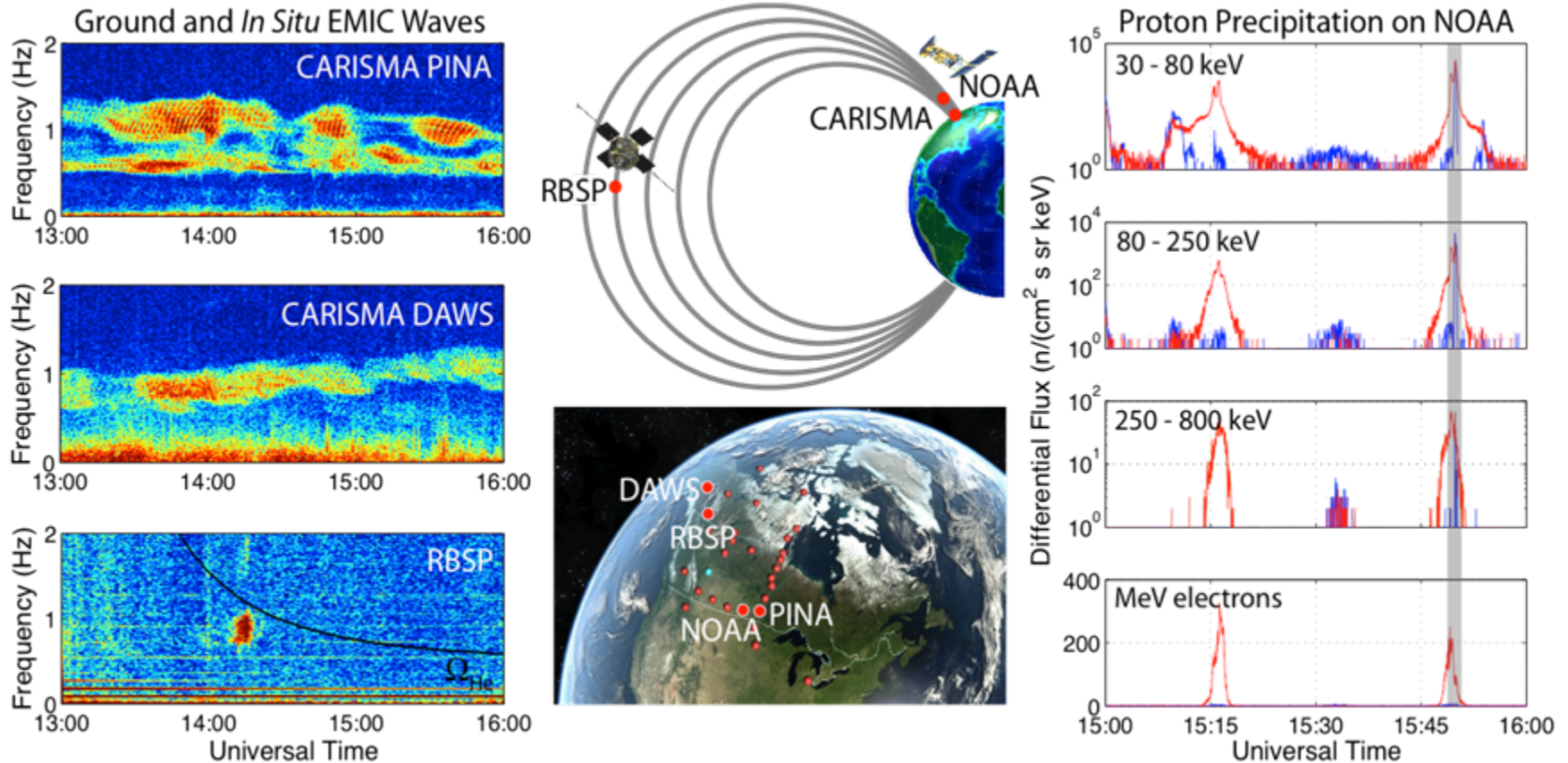
New results from the Van Allen Probes
(Radiation Belt Storm Probes) mission

Storm-time Chorus-Driven Electron Energization RBSP / EMFISIS and MagEIS

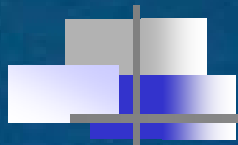


14 November 2012 storm

Ground and RBSP EMICs and Proton Precipitation at LEO



Conjugate EMIC wave observations from the CARISMA magnetometers and the Van Allen Probes together with proton loss on the LEO-orbit NOAA POES satellite on October 11, 2012



Summary

The two energetic particle populations in Geospace, the ring current and the Van Allen radiation belts, monitored and studied separately for a long time, are strongly coupled through storm-time electromagnetic waves. Several international efforts are on-going. One them is the Greek-led MAARBLE project

Acknowledgement

The work presented in this paper has received support from the European Commission (EC)'s Seventh Framework Programme through the

**Monitoring, Analyzing & Assessing
Radiation Belt Loss & Energization**
FP7-SPACE-2011-1 Collaborative Project





Shameless Ad

New Book

Waves, particles and storms in geospace

G. Balasis, I.A. Daglis and I. Mann

Contributions by:

D. Baker, R. Horne, U. Inan, G. Reeves, H. Spence, and others

to be published by Oxford University in 2014