The Abdus Salam
International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

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310/1749-43

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

The Particle Radiation Environment of the Near-Earth Space

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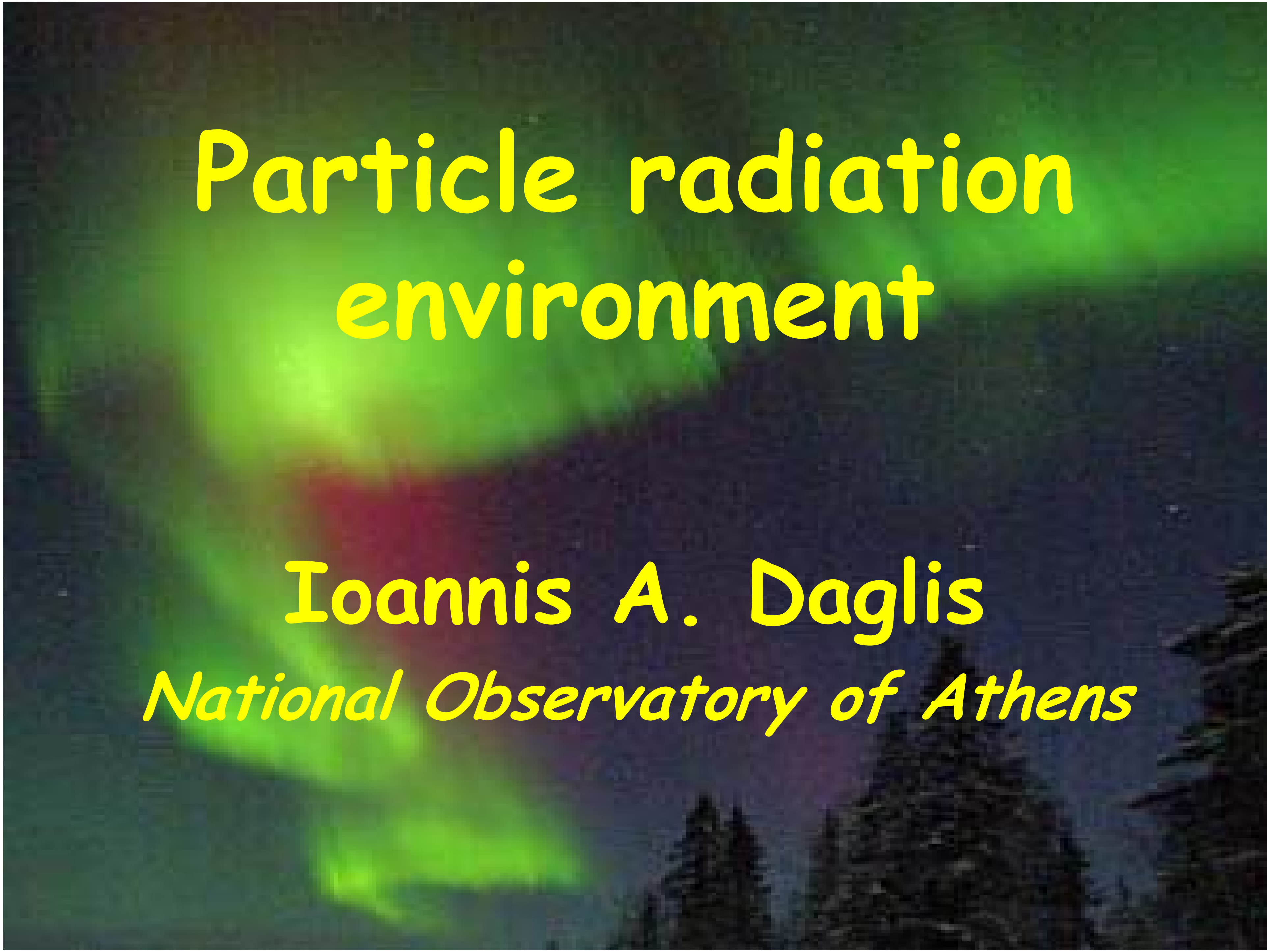
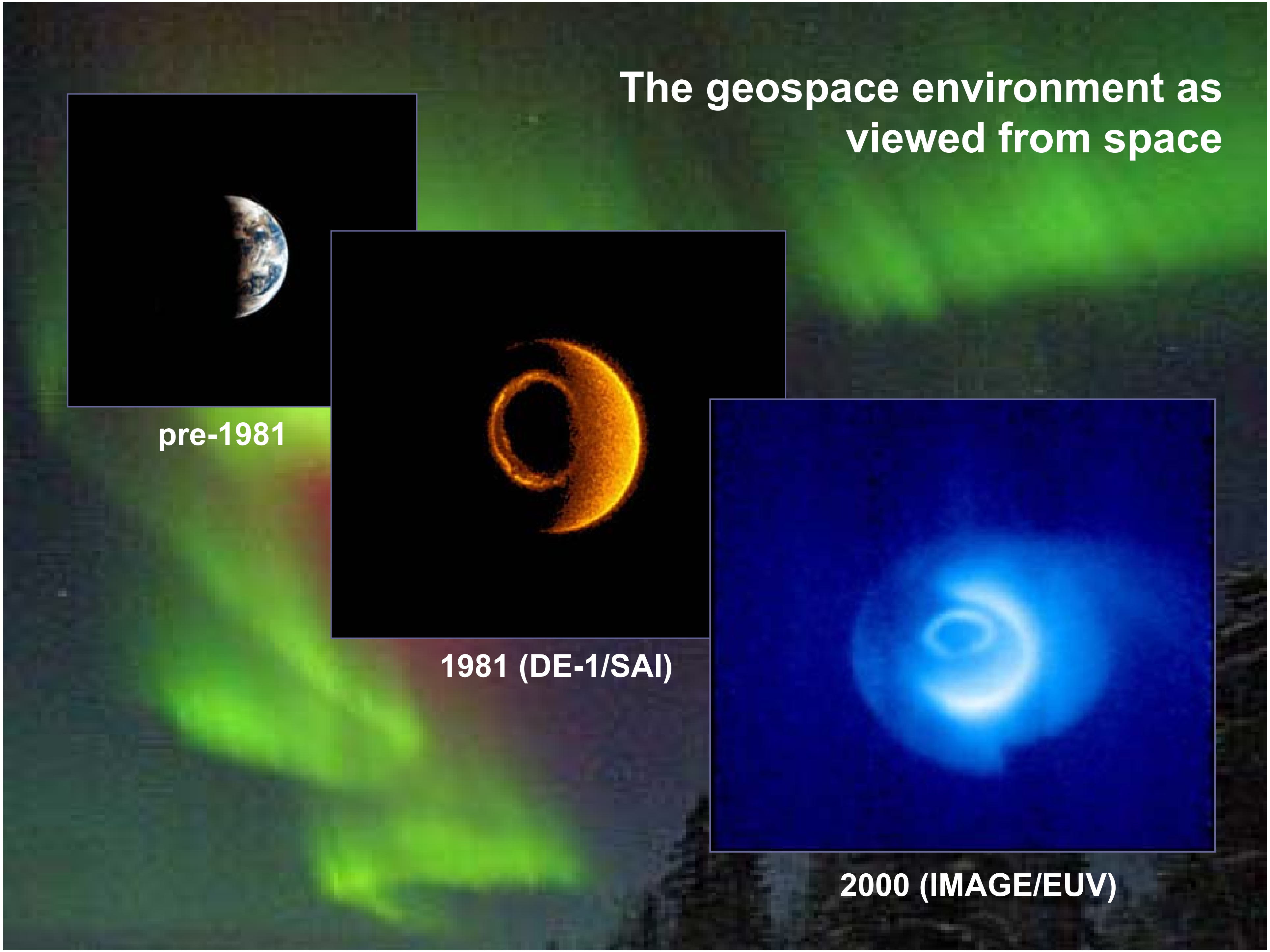
These lecture notes are intended only for distribution to participants



Particle radiation environment

Ioannis A. Daglis

National Observatory of Athens


The geospace environment as viewed from space
pre-1981
1981 (DE-1/SAI)
2000 (IMAGE/EUV)

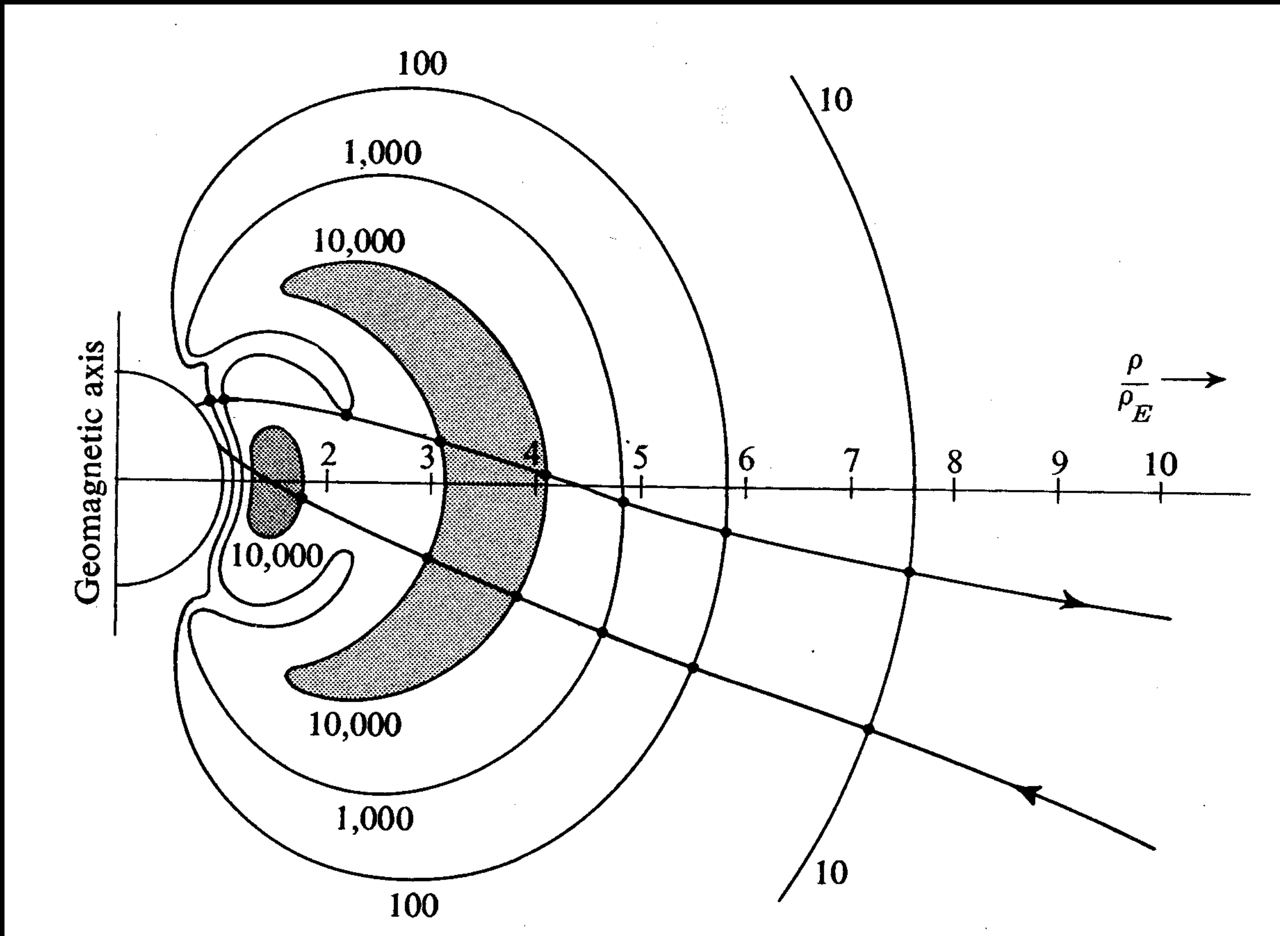
Outline

- A little bit of history
- Radiation belt features
- Radiation belt formation
- RC sources
- RC formation: IMF driver
- RC formation: role of substorms
- RC dynamic evolution & decay

A little

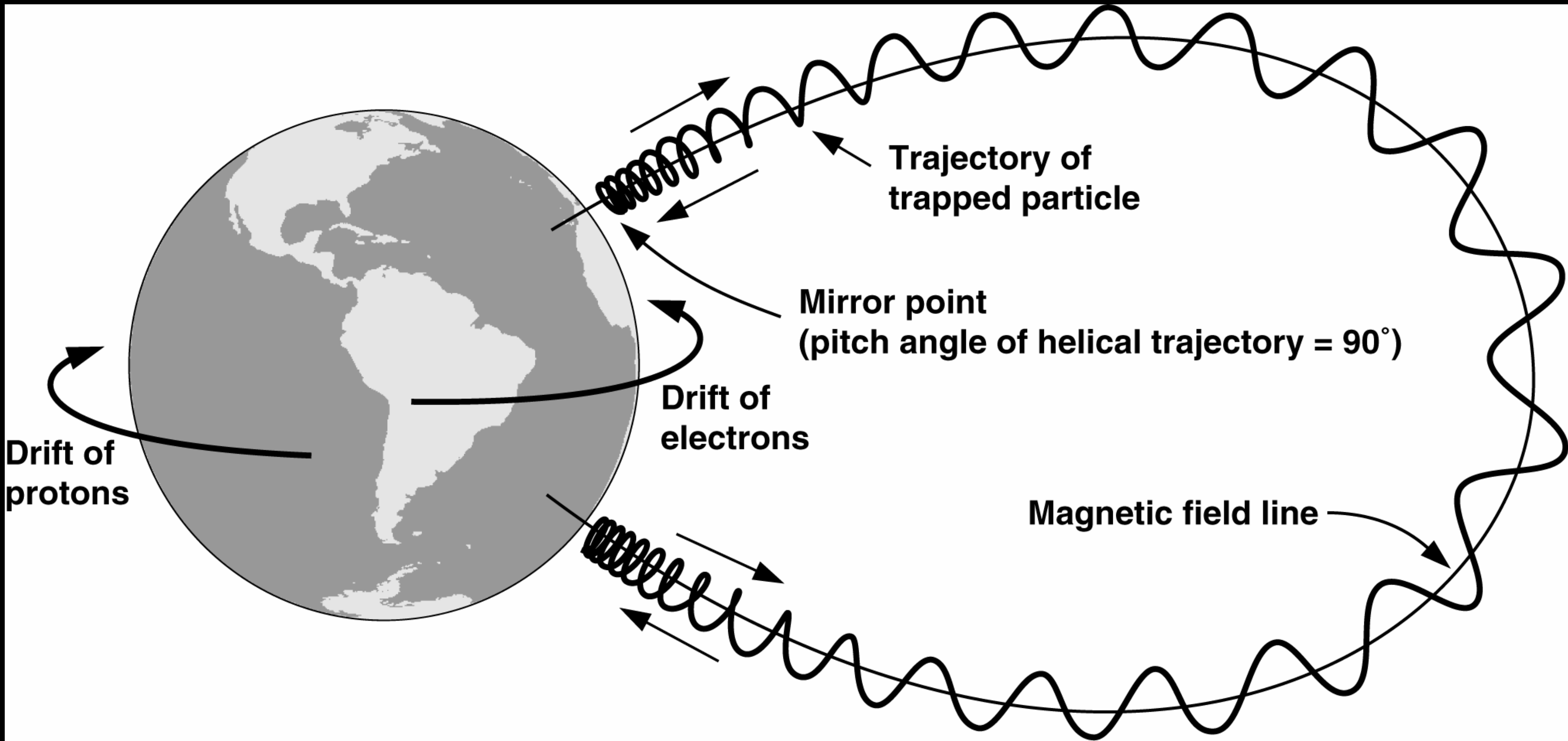
Trapped p discovery
in space – rer!

The first RB map

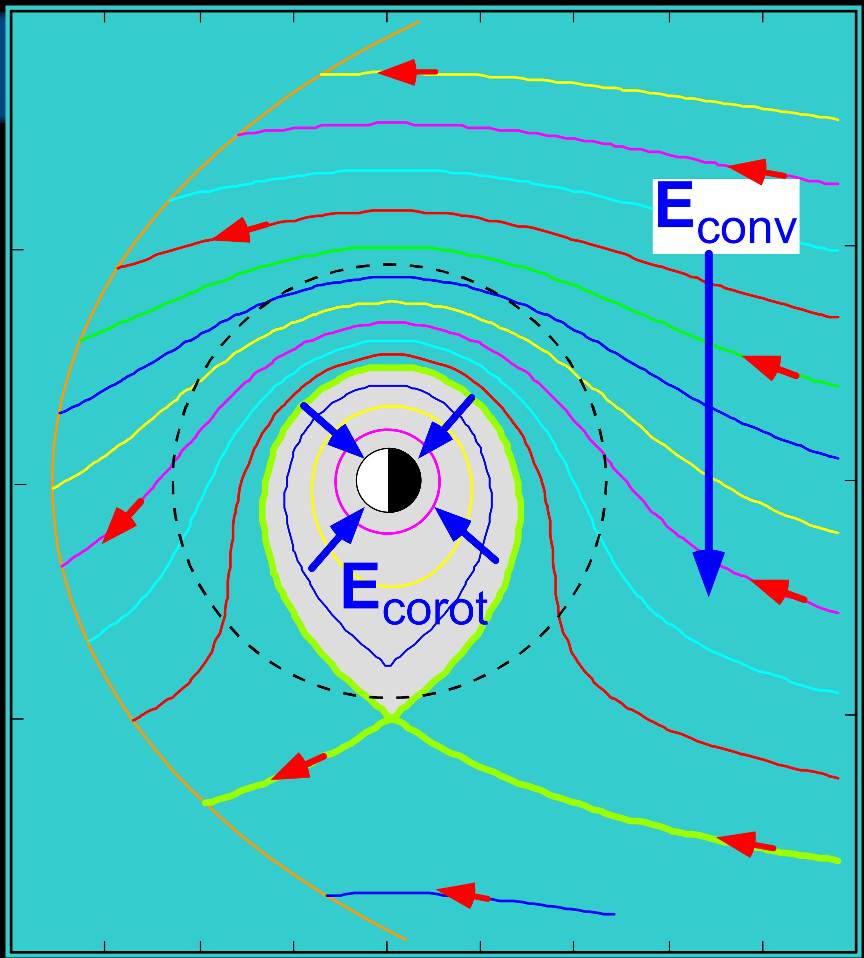


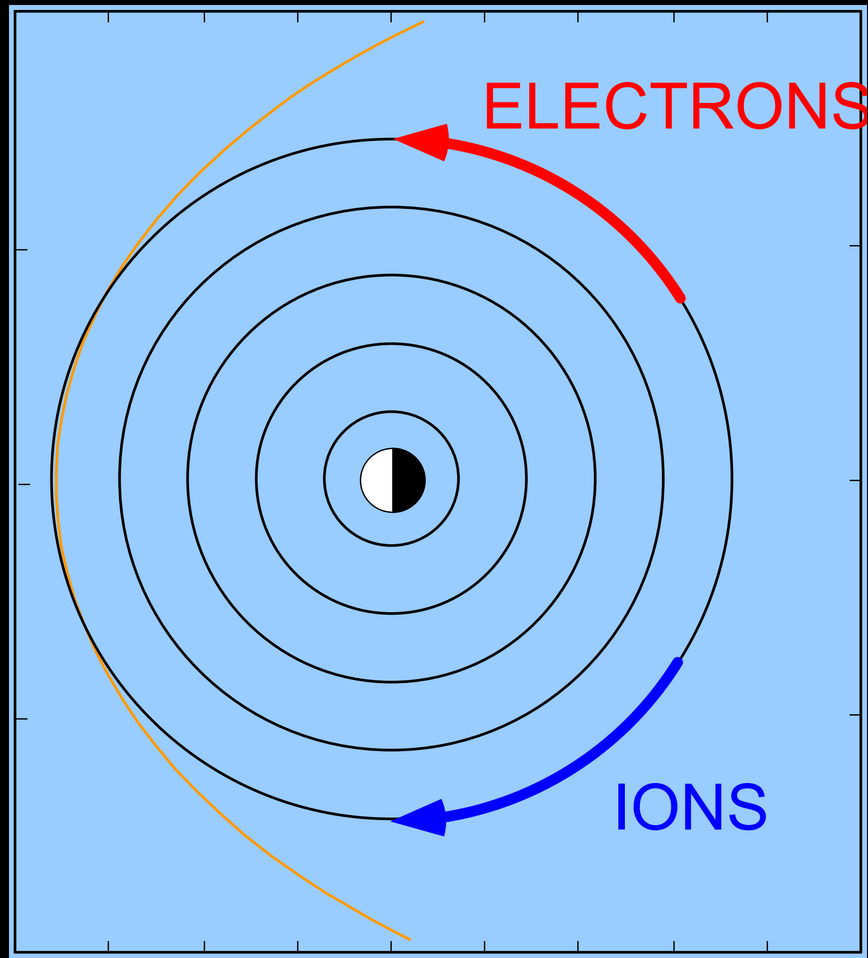
Van Allen [1959]

Trapped particle motion



Particle transport

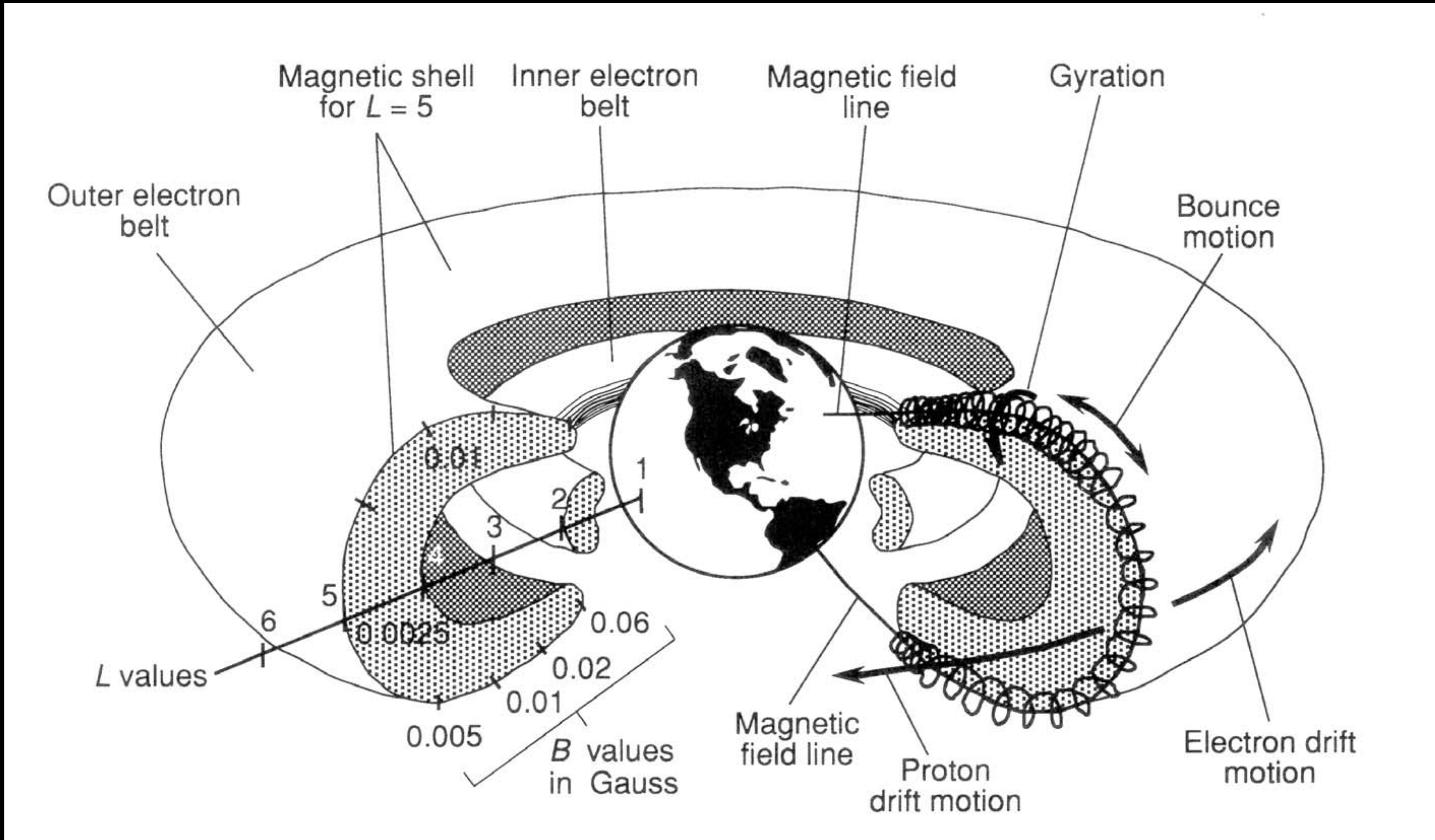




Convection + Gradient-Curvature Drift

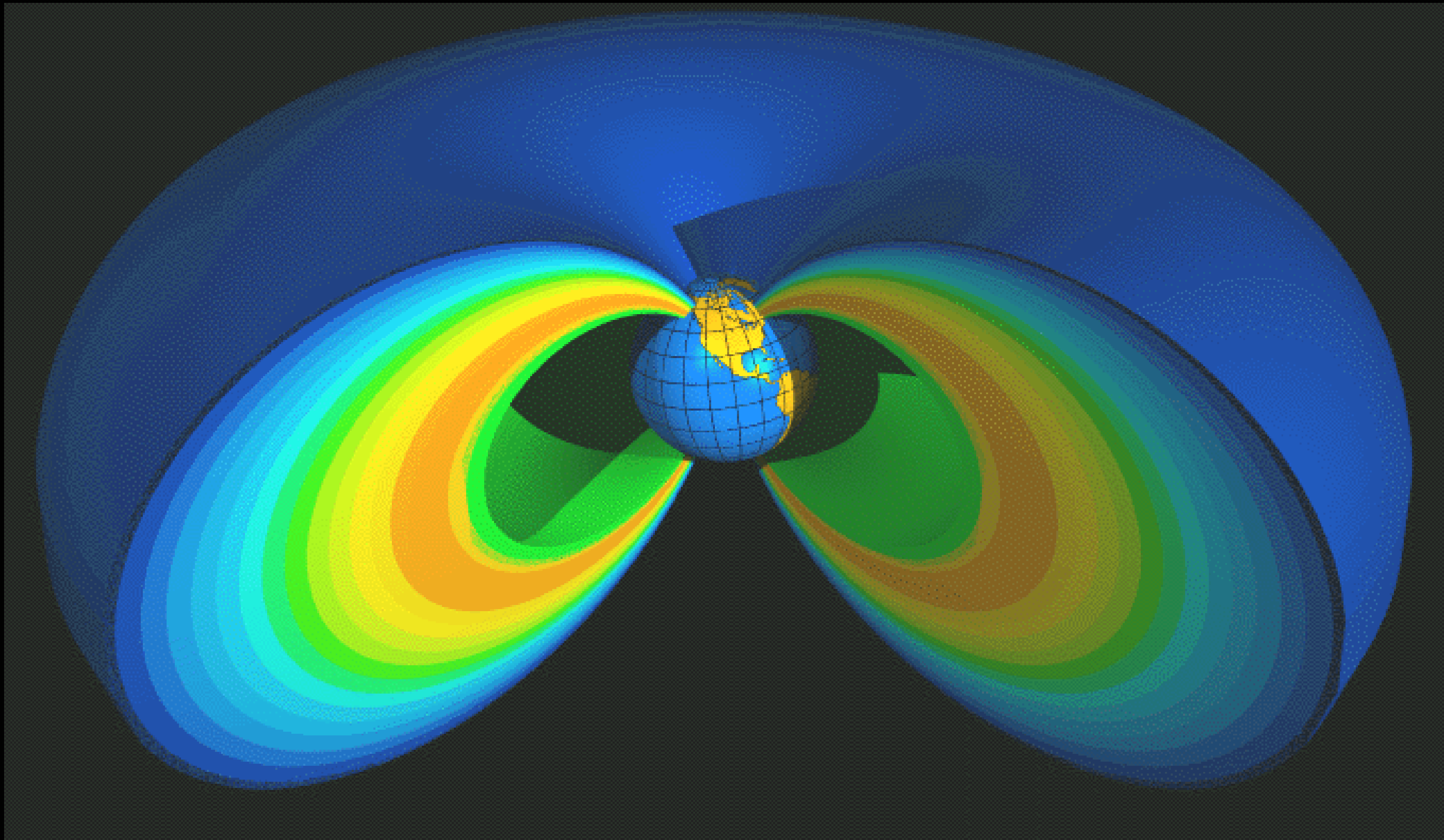
$$\mathbf{V}_D = - \quad +$$

3-D graph of inner and outer belt



Mitchell [1994]

Color 3-D view



Why study the radiation belts?

- Because they're physically interesting!
- Relativistic electrons have been associated with spacecraft 'anomalies'.

Radiation belt principles

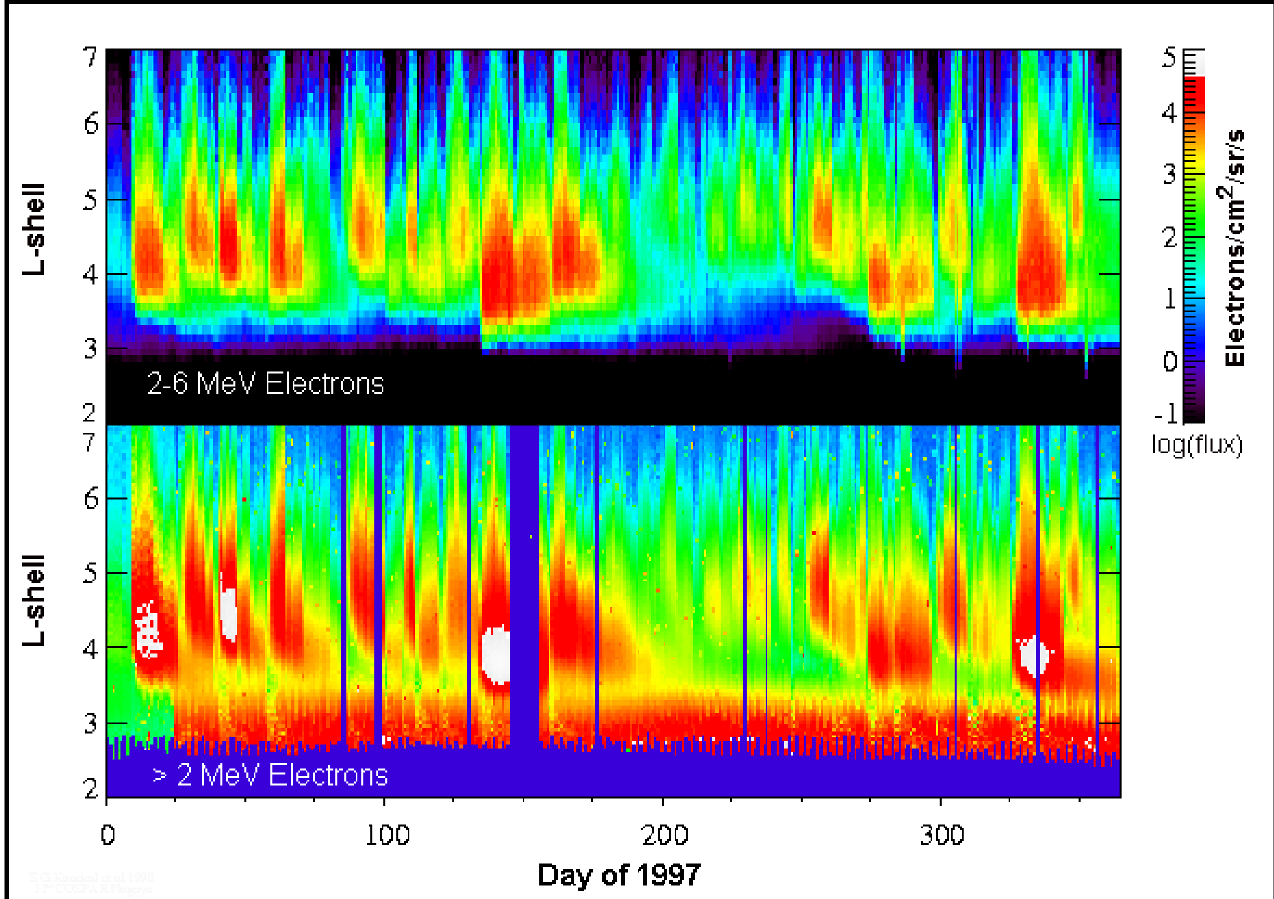
A pre-requisite of relativistic (MeV) electron enhancement is typically an interval of southward IMF along with a period of high solar wind speed (V≥500 km/s).

A second step is found to be a period of intense wave activity.

Accordingly, substorms appear to provide a "seed" population, while high-speed solar wind drives the acceleration to relativistic energies in this two-step scenario.

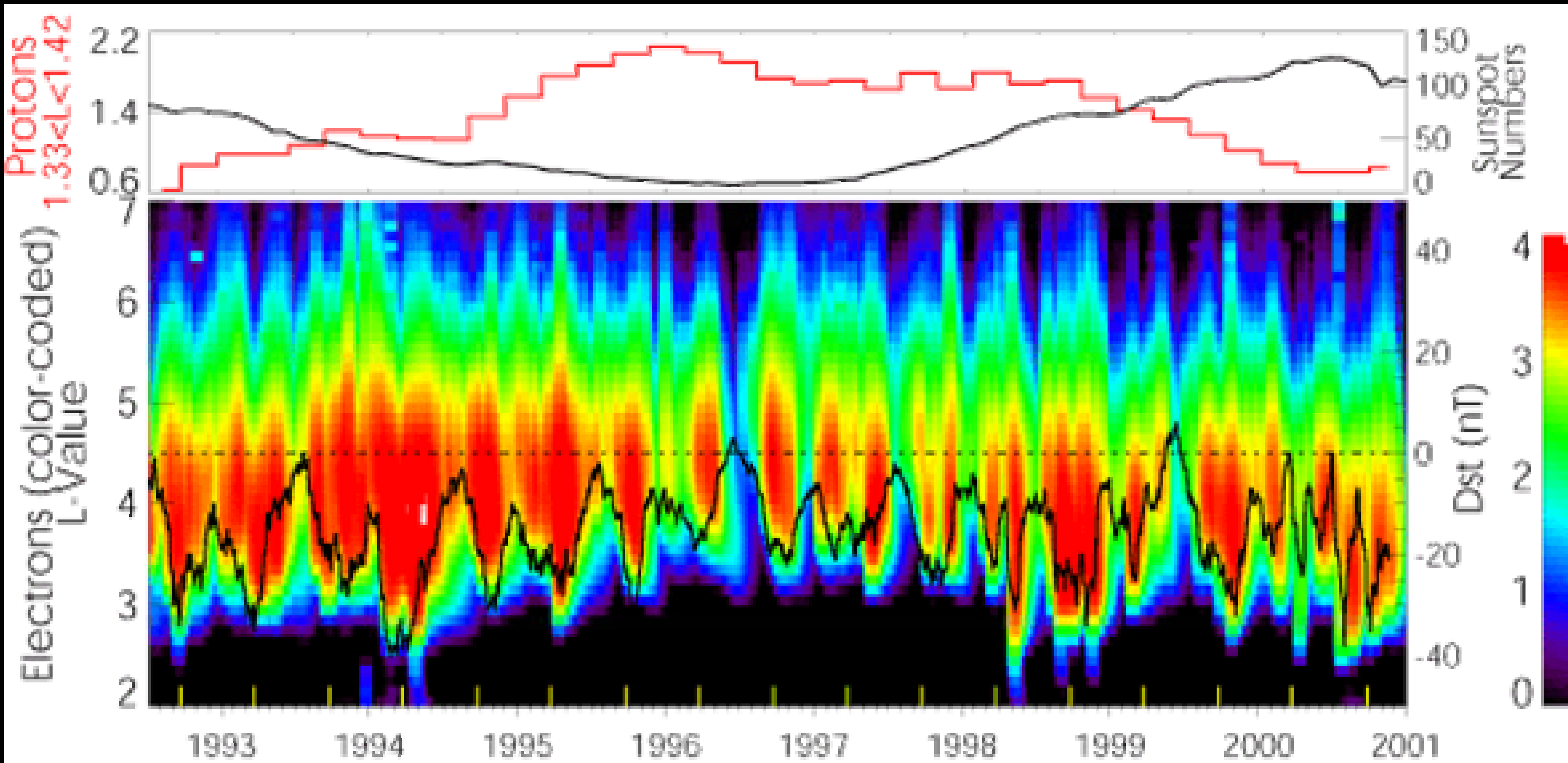
Fluxes in the radiation belts

The radiation belts exhibit substantial variation in time:



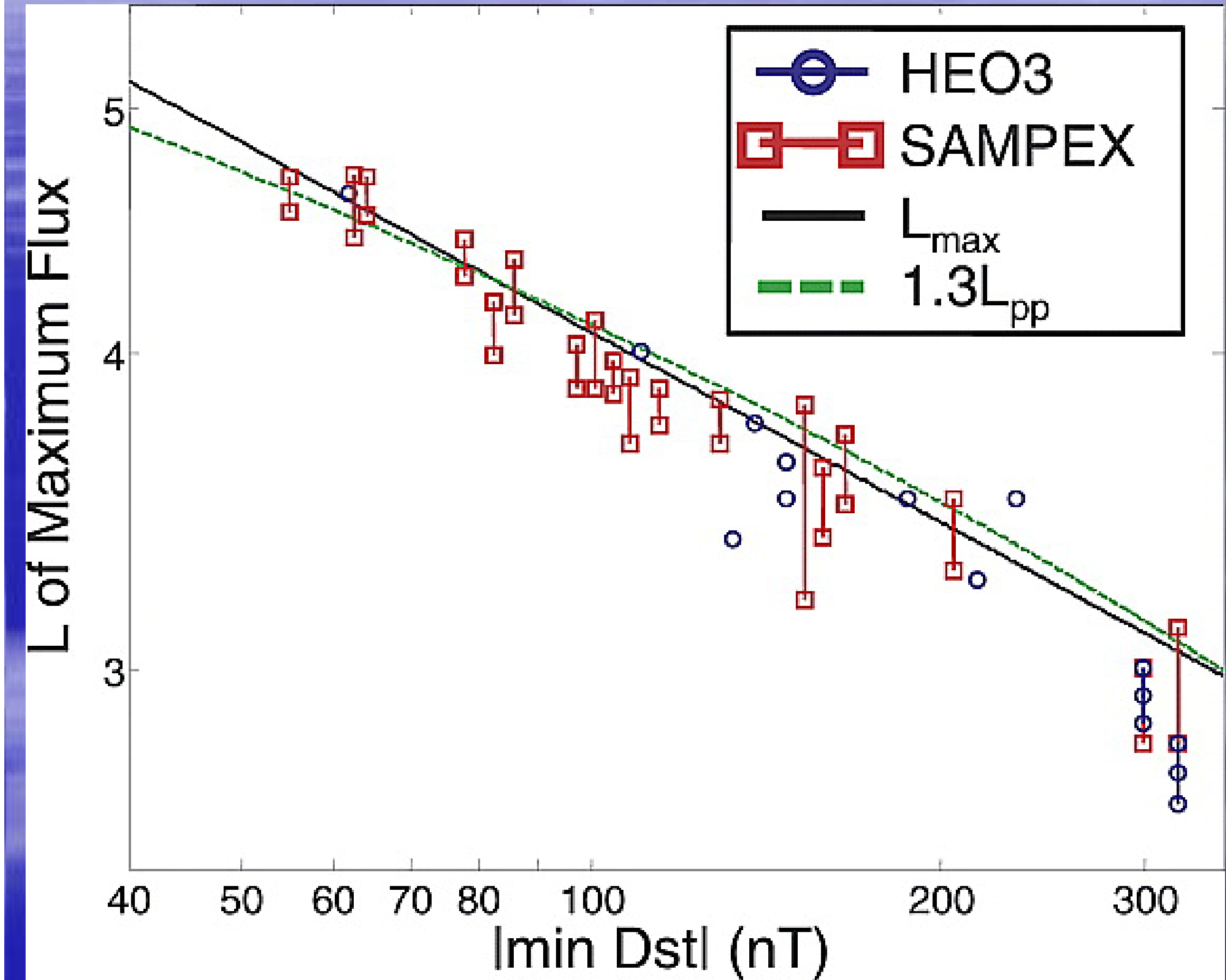
- Storm commenc.: minutes
- Storm main phase: hours
- Storm recovery: days
- Solar rotation: 13-27 days
- Season: months
- Solar cycle: years

Correlation with magnetic storms



Fluxes vary from 10 to 10^4 (Li et al. 2001).

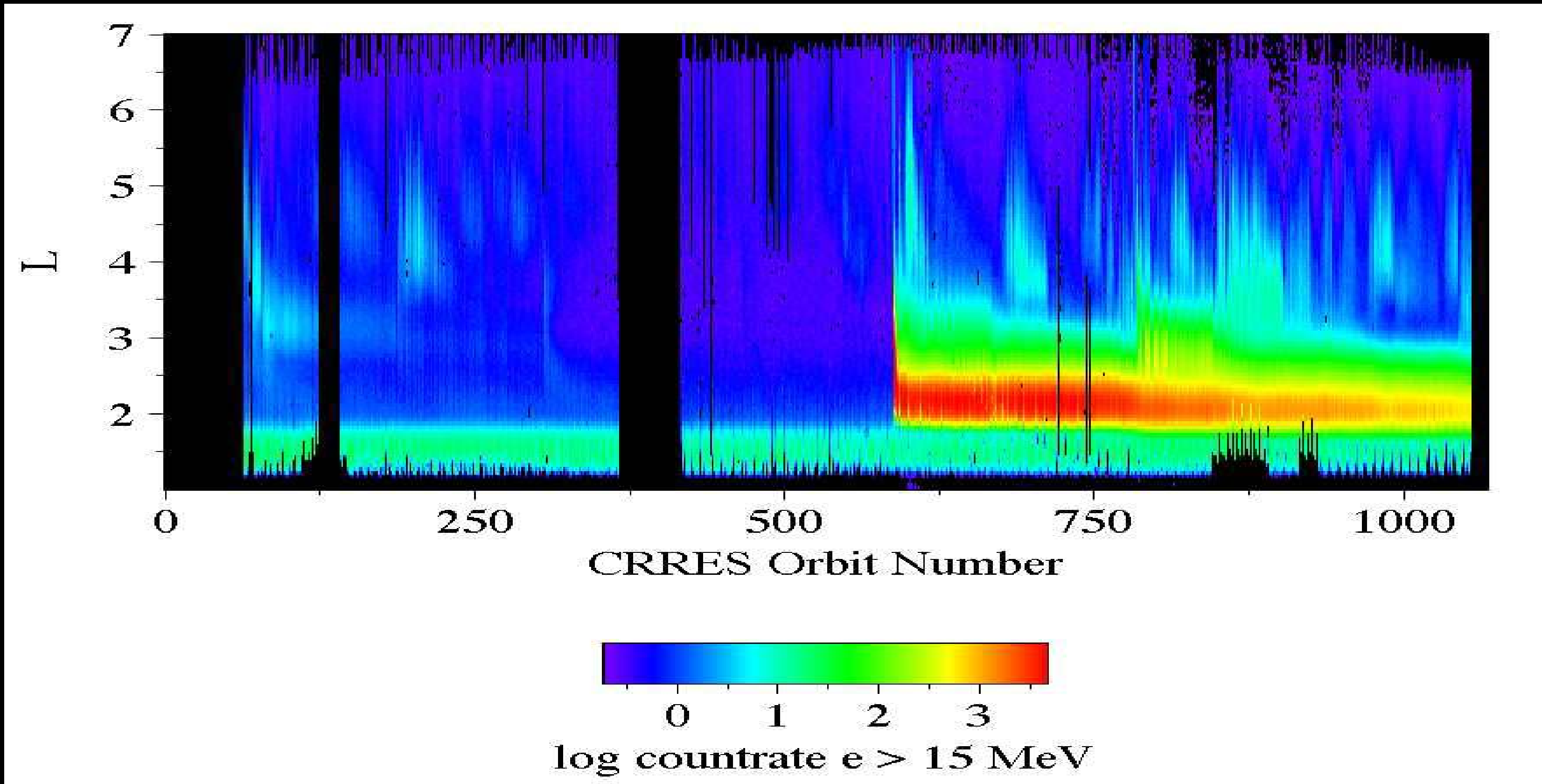
Correlation with magnetic storms



Location of the peak electron flux as a function of minimum Dst moves to lower L

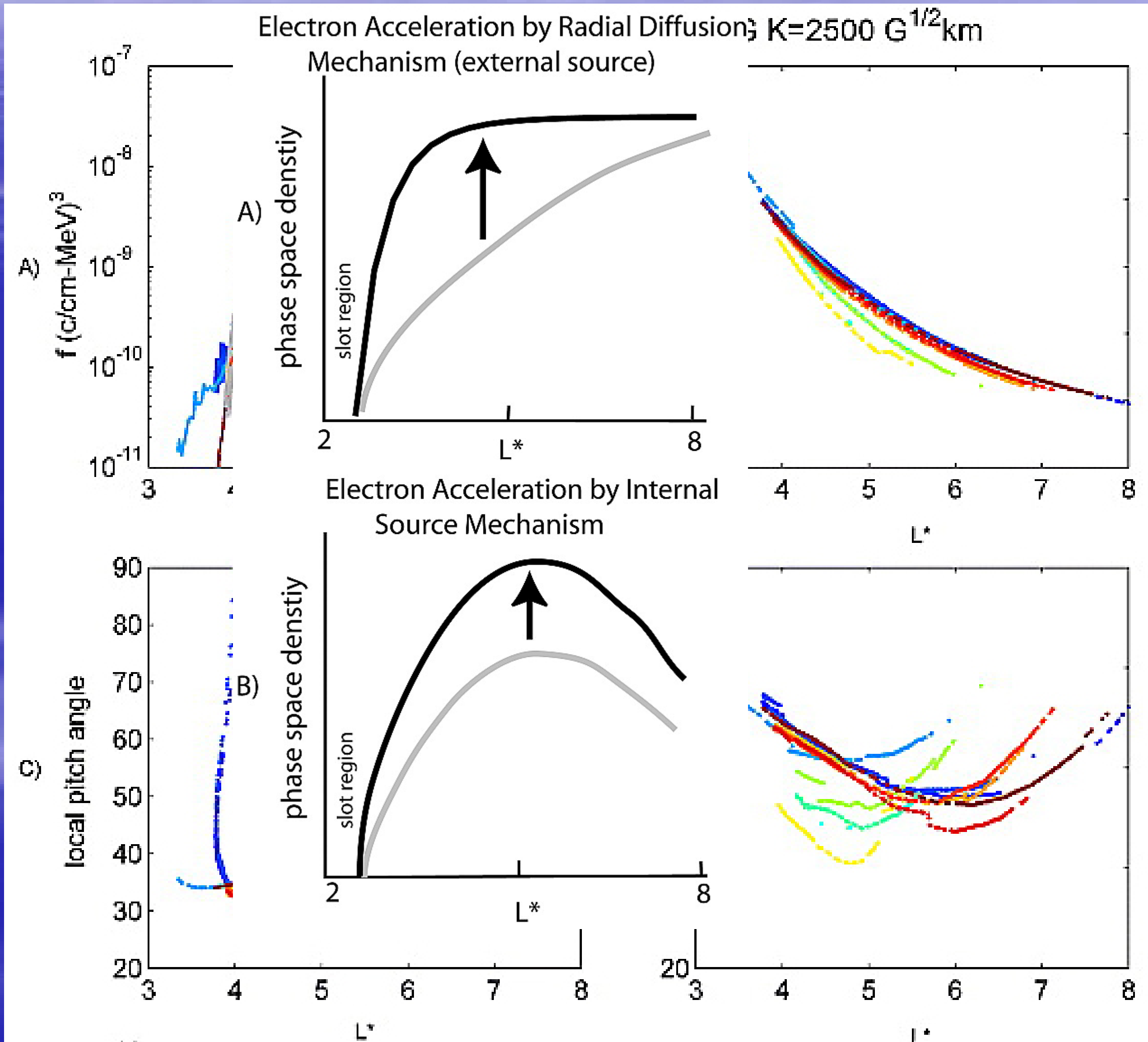
O'Brien et al., JGR2003

Effects of intense storms

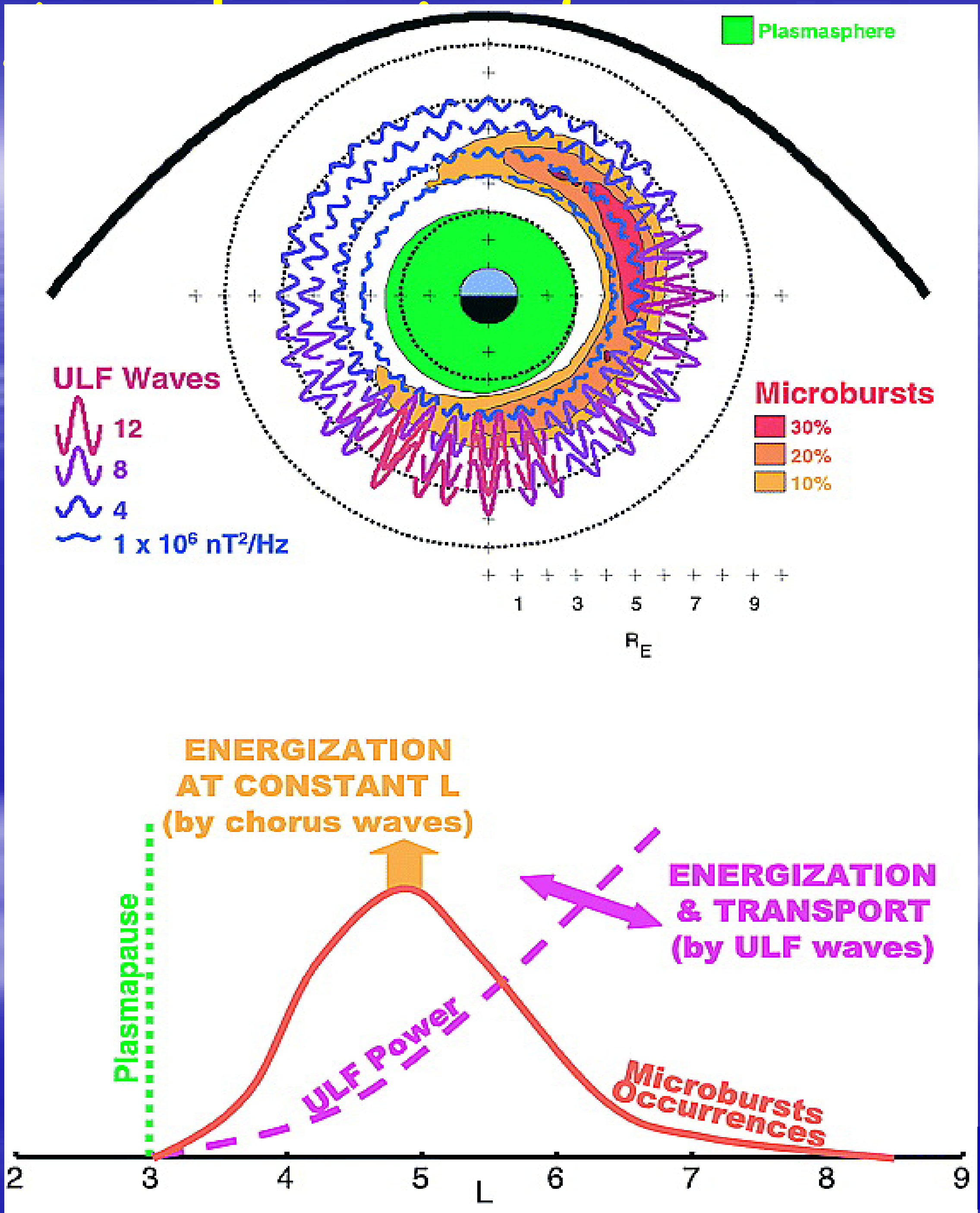


(CRRES, Bernie Blake)

Radiation belt acceleration: radial diffusion, or …?



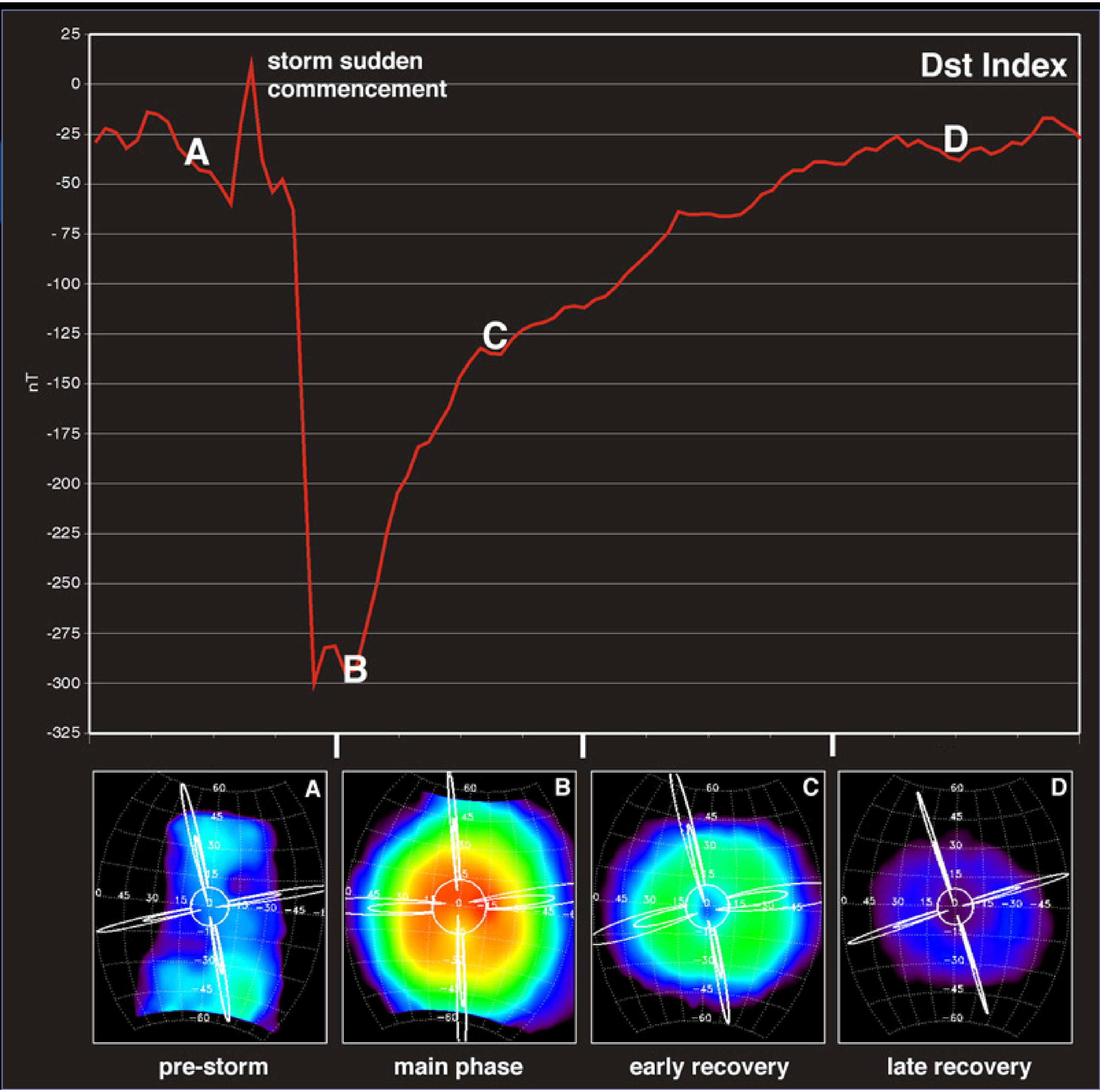
Green and Kivelson, 2004

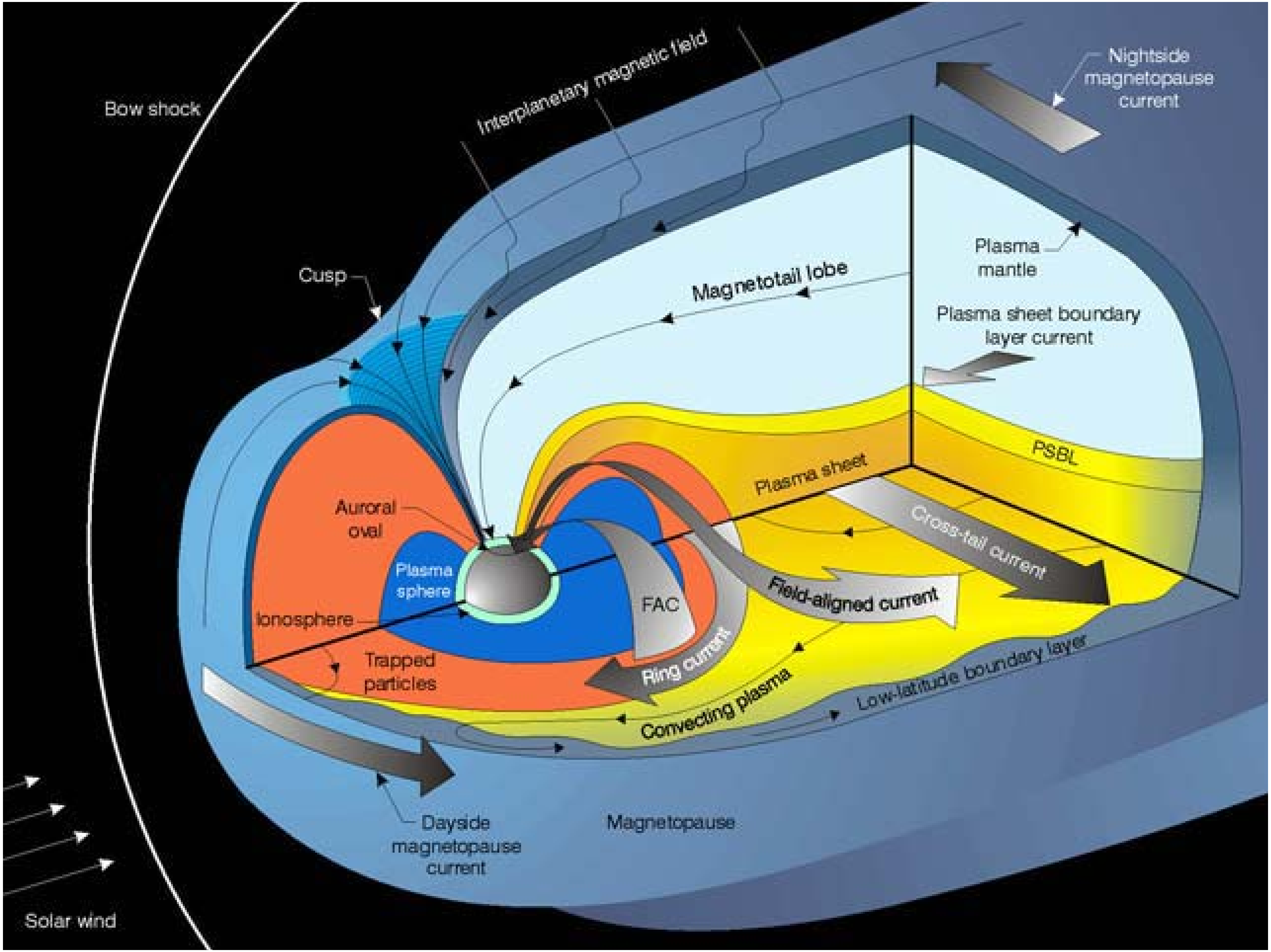


O'Brien et al., JGR2003

Ring Current

- “Principles” and historical review
- RC sources
- RC formation: IMF driver
- RC formation: role of substorms
- Dynamic evolution & decay


Dst Index
storm sudden
commencement
A
B
C
D
nT
25
0
-25
-50
-75
-100
-125
-150
-175
-200
-225
-250
-275
-300
-325
pre-storm
main phase
early recovery
late recovery



Bow shock
Interplanetary magnetic field
Nightside magnetopause current
Plasma mantle
Cusp
Magnetotail lobe
Plasma sheet boundary layer current
PSBL
Plasma sheet
Auroral oval
Cross-tail current
Plasma sphere
FAC
Field-aligned current
Ionosphere
Ring current
Trapped particles
Low-latitude boundary layer
Convecting plasma
Dayside magnetopause current
Magnetopause
Solar wind

Ring current - the classical picture

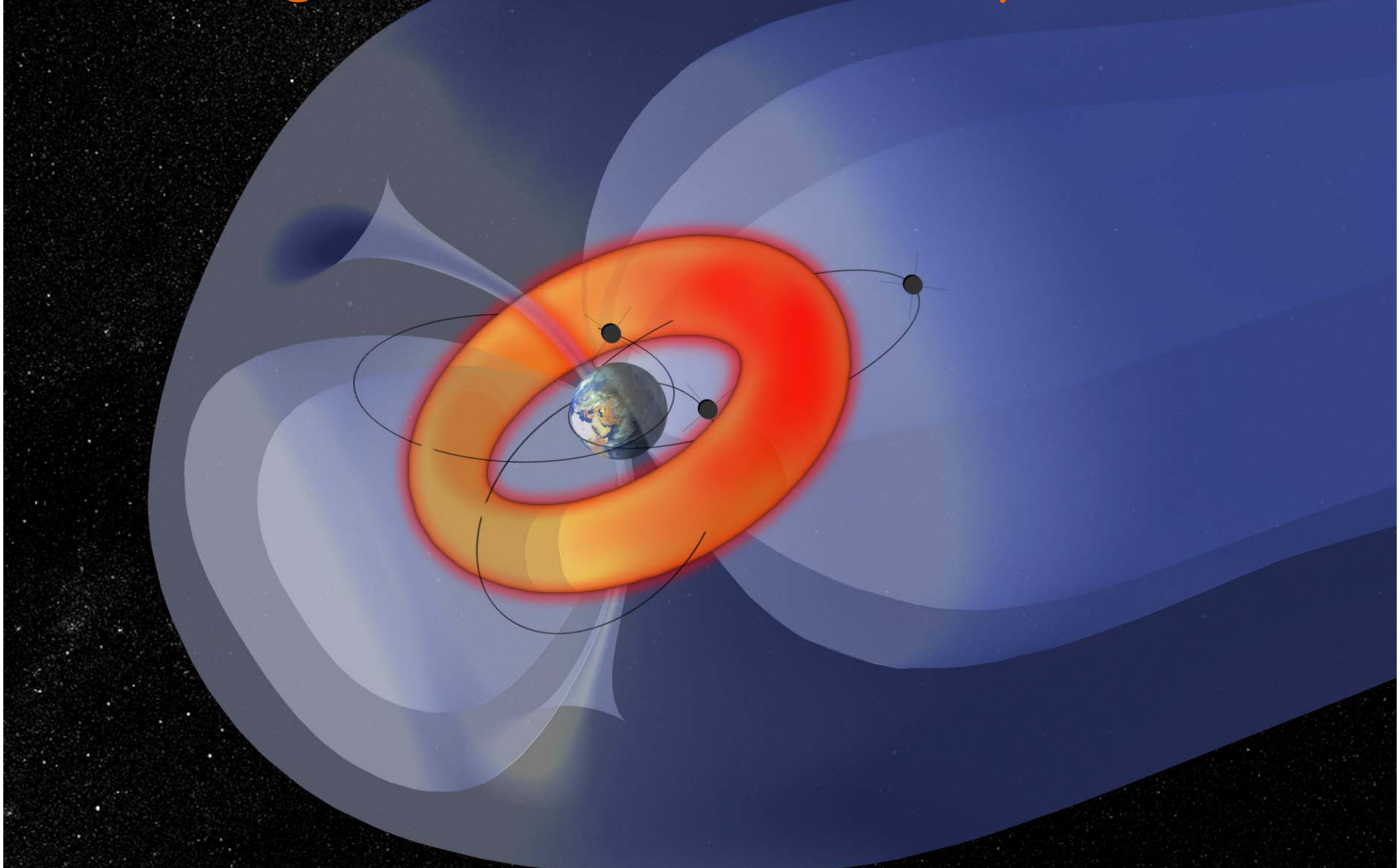
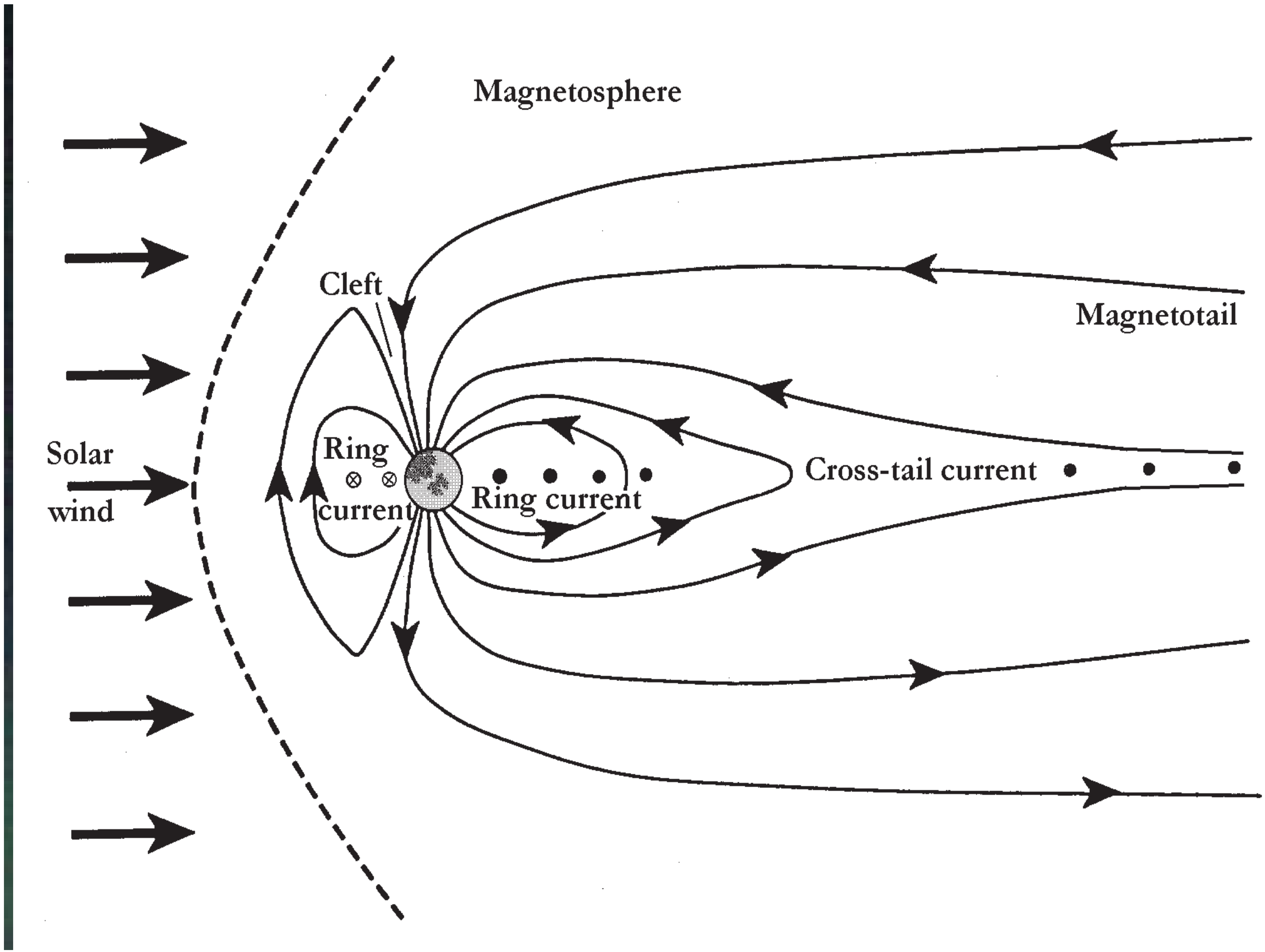


Image courtesy Hannu Koskinen, FMI



Magnetosphere
Cleft
Magnetotail
Solar
wind
Ring
current
Ring current
Cross-tail current

Ring Current History

Milestones in ring current concept

- 1930, Chapman: a transient stream of outflowing solar ions and electrons are responsible for terrestrial magnetic storms
- 1956, Singer: particles from the Sun enter the trapping regions; their gradient drift carries a westward electric current, which decreases the horizontal component of the geomagnetic field

The times are changing …

Bob Dylan

Ring Current and Dst:

the "classic perfect couple" representing the "size" of geospace magnetic storms have lost their "omnipotence".

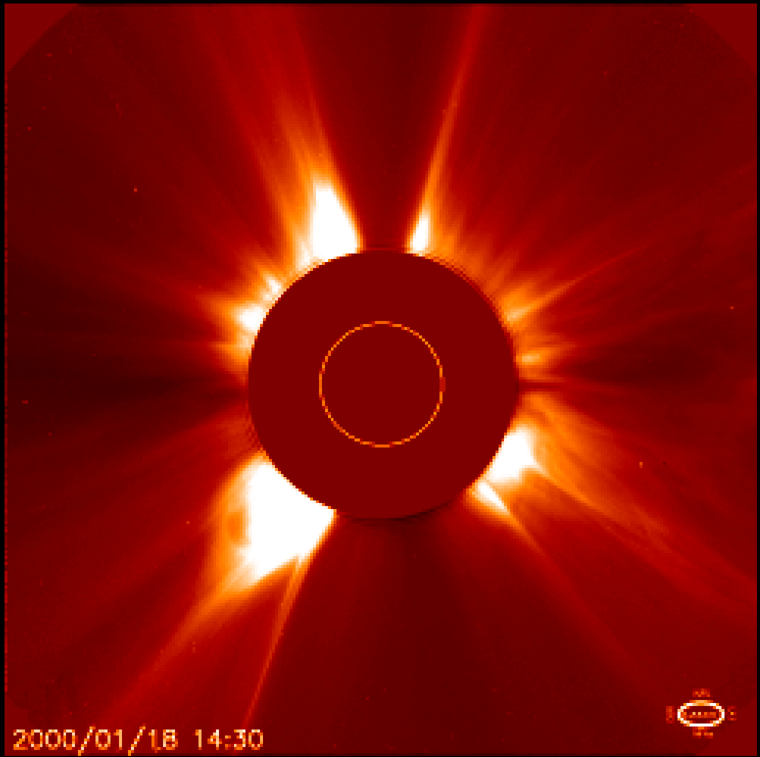
RC: Not a perfect ring; not the most important aspect of storms (increasingly important: relativistic RB electrons).

Dst: **The** index measures more than just RC intensity.

Ring Current

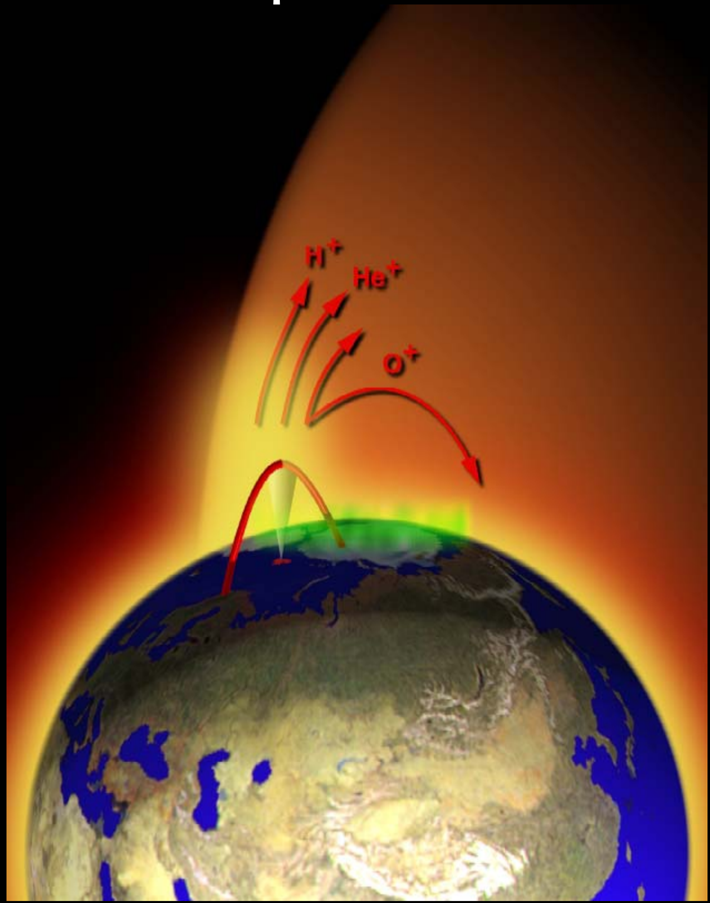
- “Principles” and historical review
- **RC sources**
- RC formation: IMF driver
- RC formation: role of substorms
- Dynamic evolution & decay

Ring current sources



The solar atmosphere

The terrestrial atmosphere

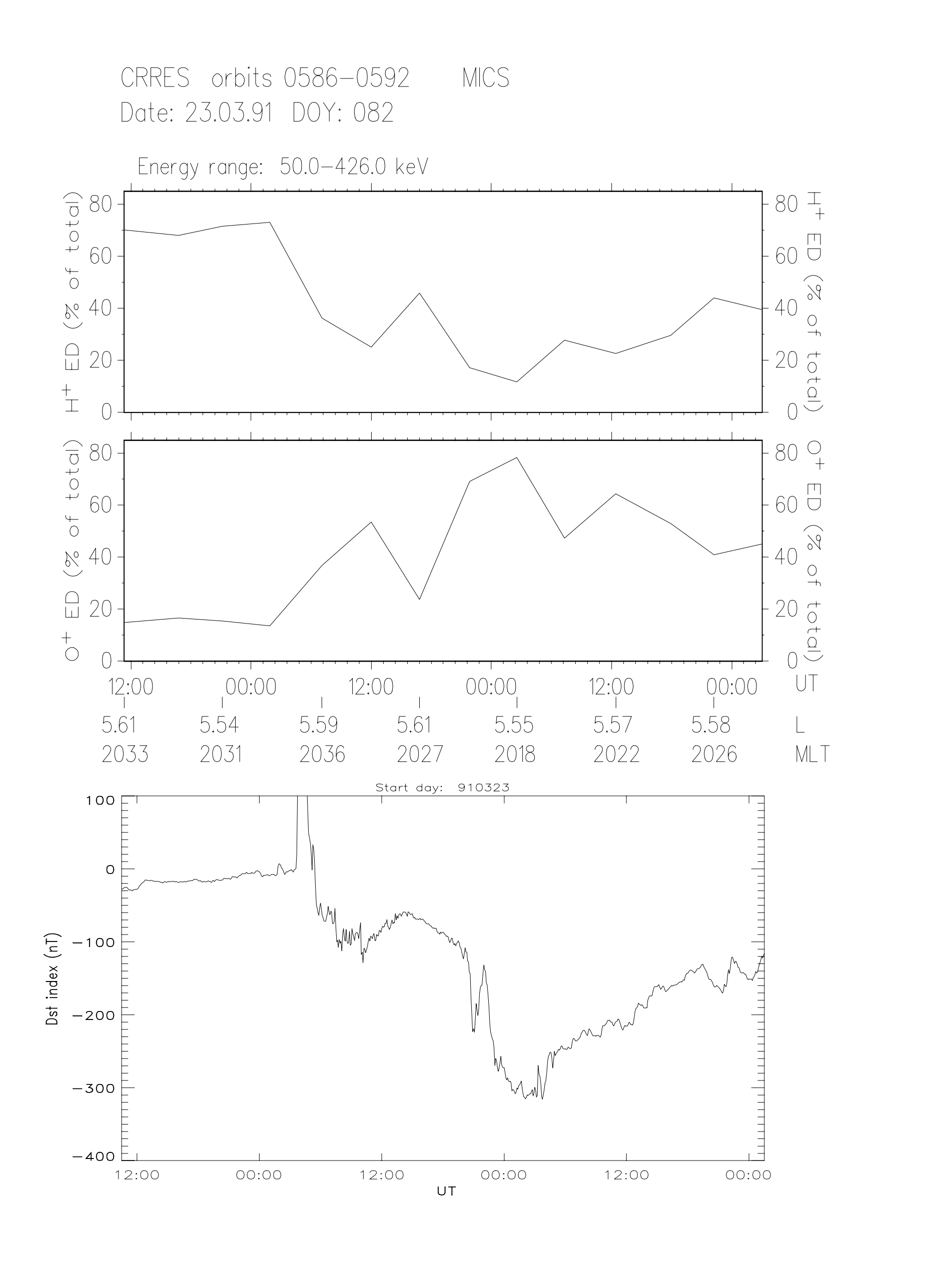


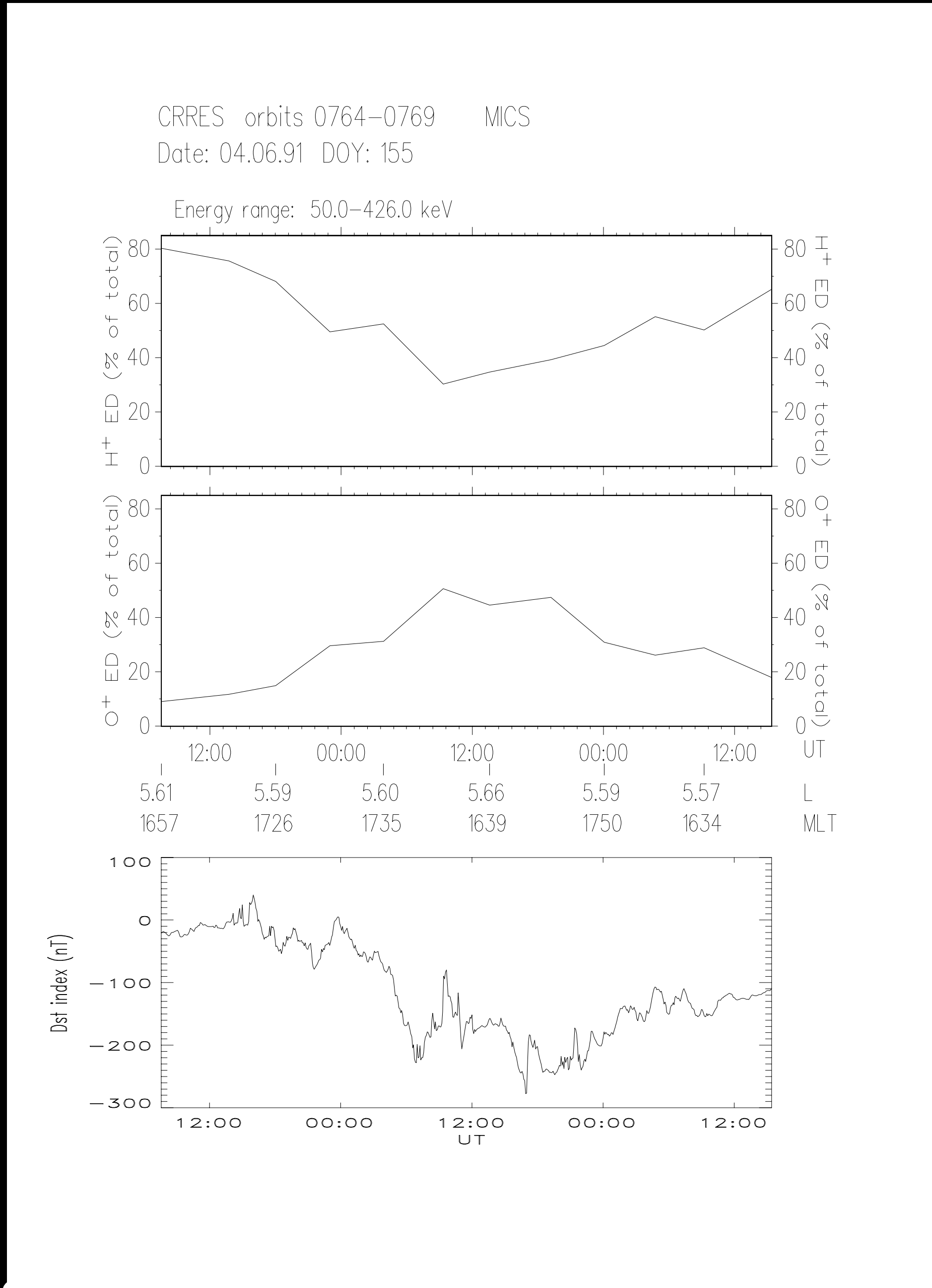
Ring Current Sources - History

Sources of ring current particles

- 1960s: solar origin
- 1972: discovery of oxygen ions
- 1988: first complete compositional measurements by AMPTE/CCE H88
- 1997: terrestrial dominance in all intense storms observed by CRRES

Ring Current Sources





Daglis, Magnetic Storms Monograph [1997]

Ring Current Sources

The upper atmosphere of our planet is an "increasingly important" source, with important implications:

It influences

RC growth and final intensity (directly and through the plasma sheet density)

RC decay (because of its short charge-exchange lifetime)

Ring Current

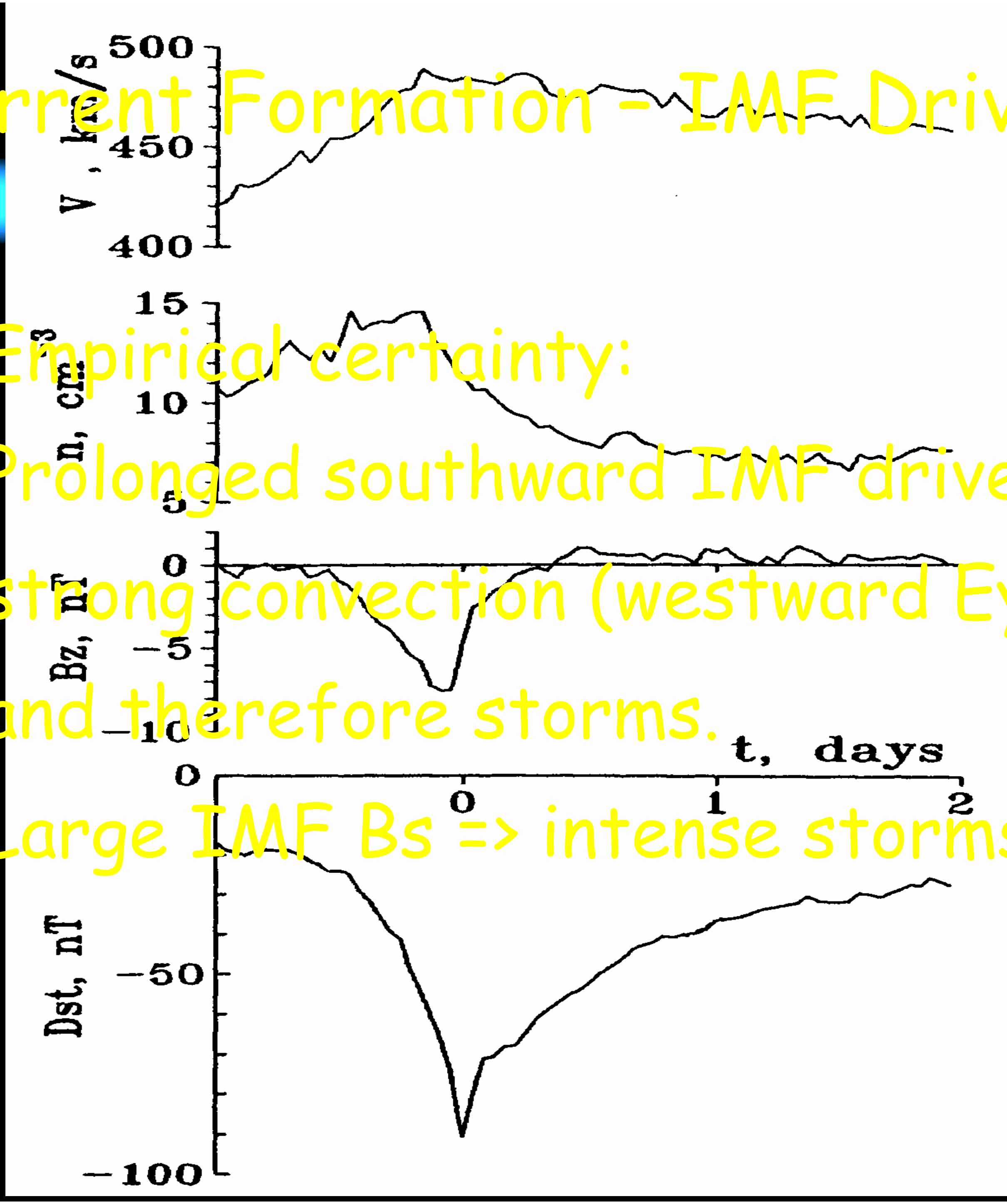
- "Principles" and historical review
- RC sources
- **RC formation: IMF driver**
- RC formation: role of substorms
- Dynamic evolution & decay

Ring Current Formation – IMF Driver

Empirical certainty:

Prolonged southward IMF drives strong convection (westward Ey) and therefore storms.

Large IMF Bs => intense storms.



Ring Current Forn

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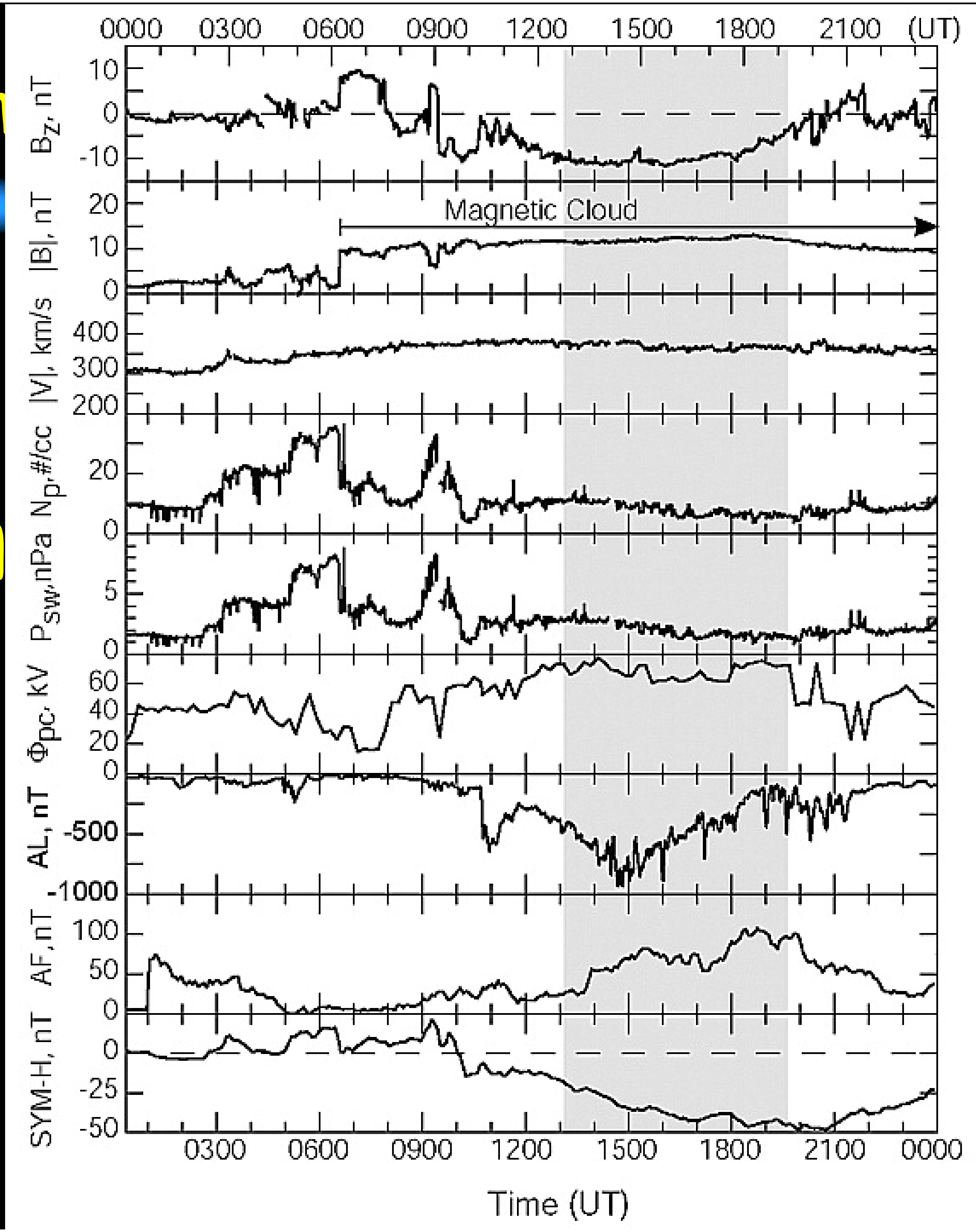
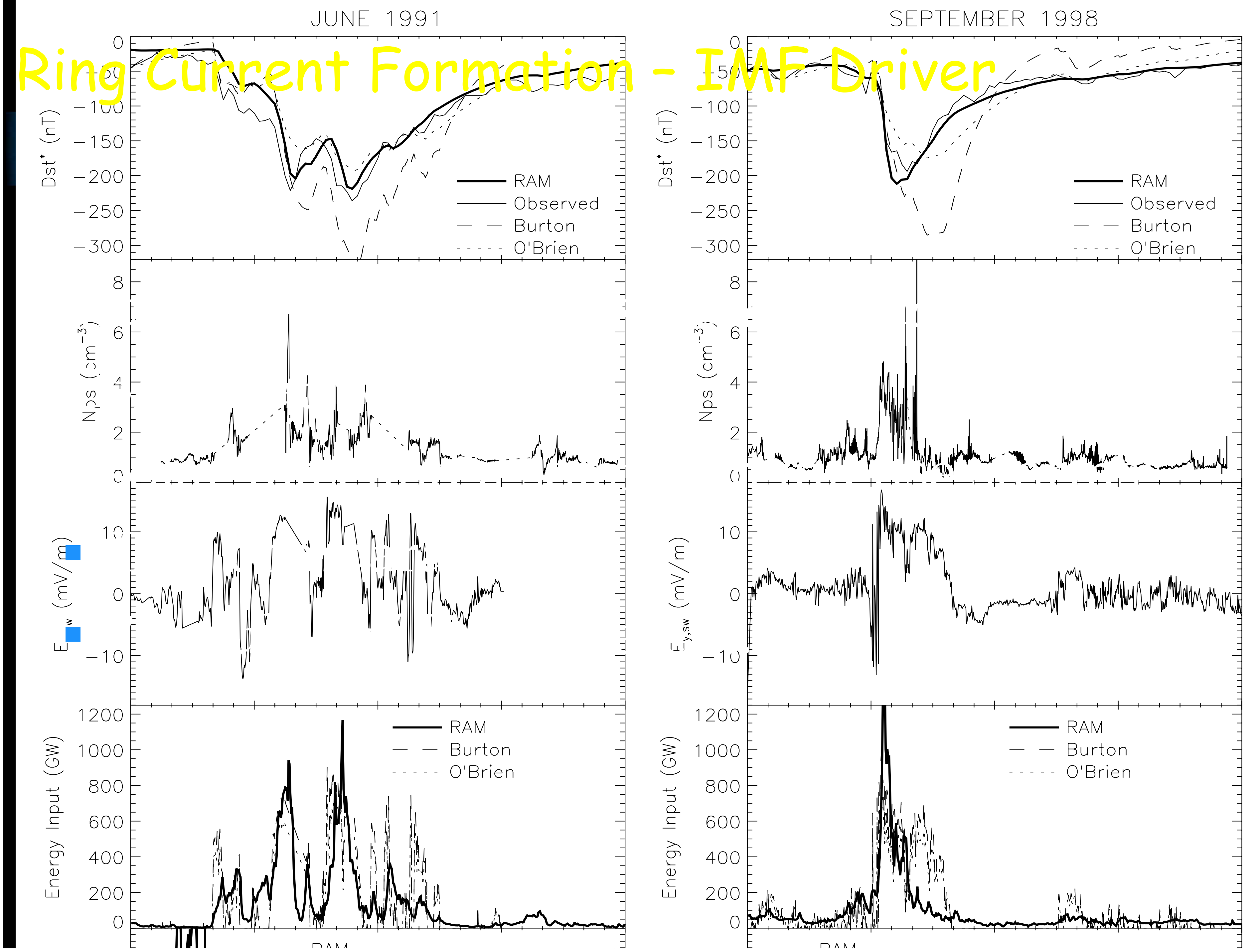


July 1997 storm,
Fig. 3 of *Zhou et al.*,
JGR 2003

Ring Current Formation - IMF Driver

Possible reason:
IMF/convection engine not sufficient:
Absence of intense substorms –
weak outflows –
(lower plasma sheet density) –
weaker ring current.

Ring Current Formation - IMF Driver



Ring Current Formation - IMF Driver

Storm intensity defined by

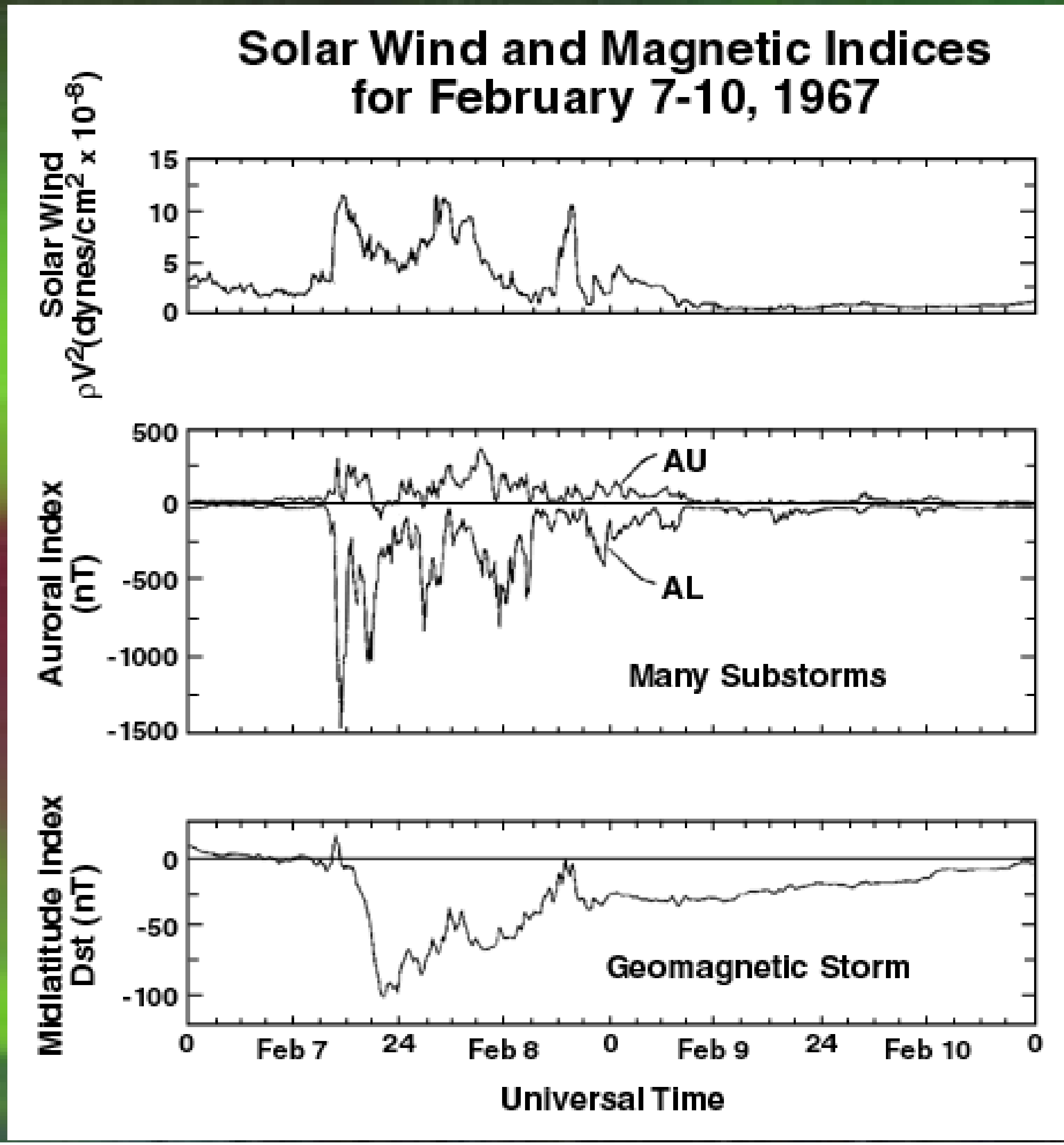
IMF Bs size and duration?

Not exclusively!

Ring Current

- **"Principles" and historical review**
- **RC sources**
- **RC formation: IMF driver**
- **RC formation: role of substorms**
- **Dynamic evolution & decay**

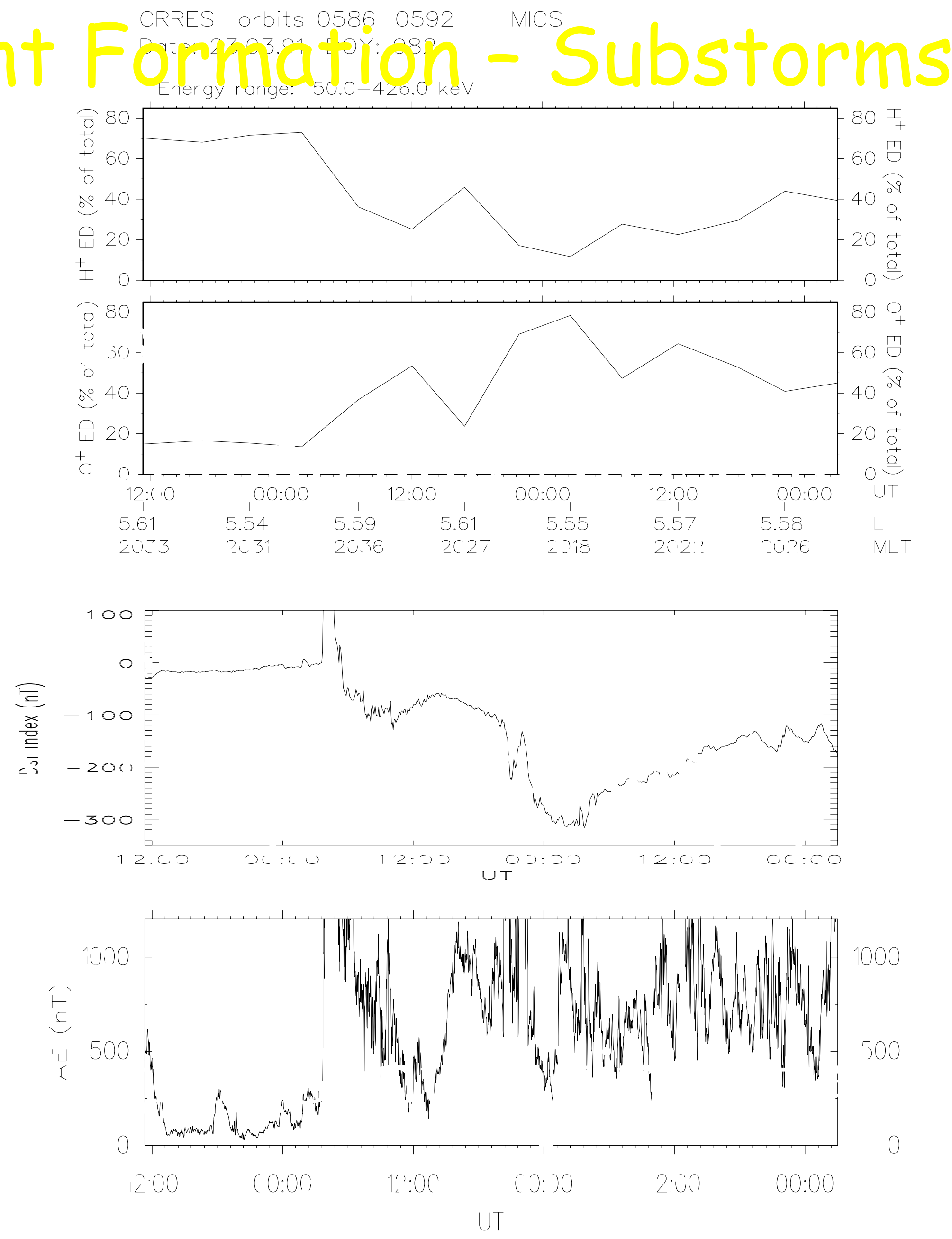
Storms and substorms



Ring Current Formation – Substorms

Role o

- 1960
  storm
  subs
- 1990
  pure
  influ
- 2000
  subs



Daglis [1997, 1999]

Ganushkin
showed t
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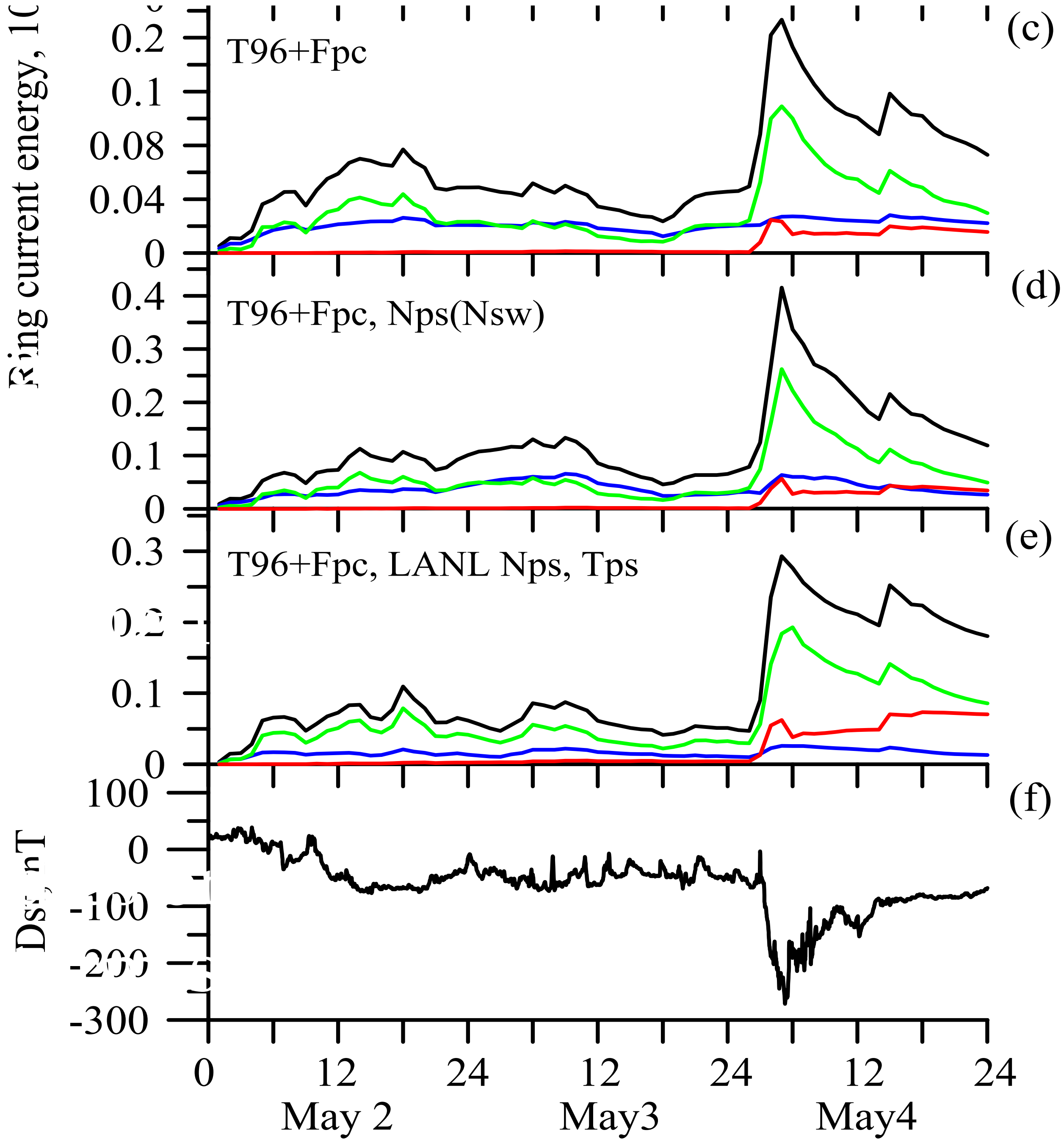


Fig. 5 of *Ganushkina et al.*, AnnGeo2005

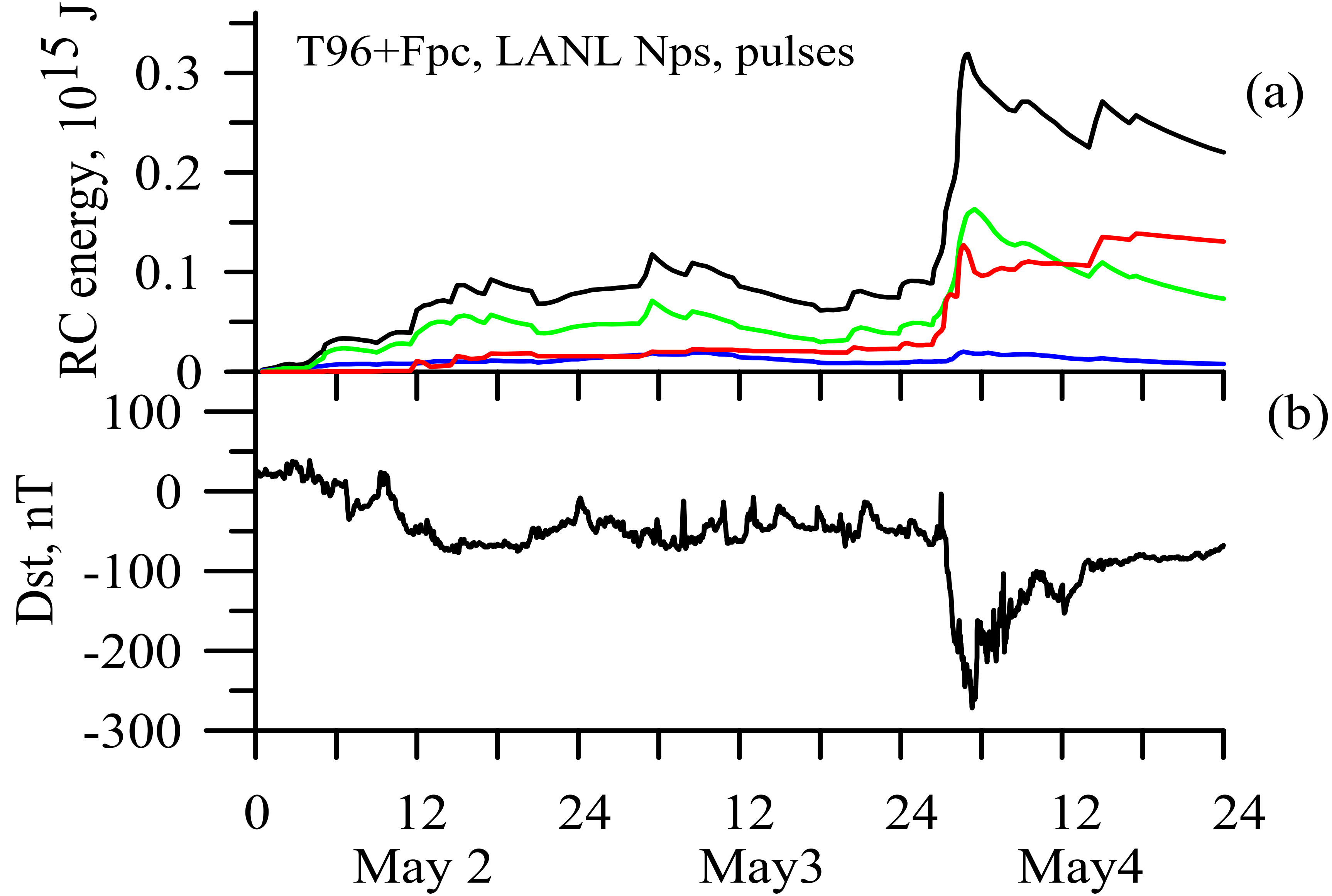
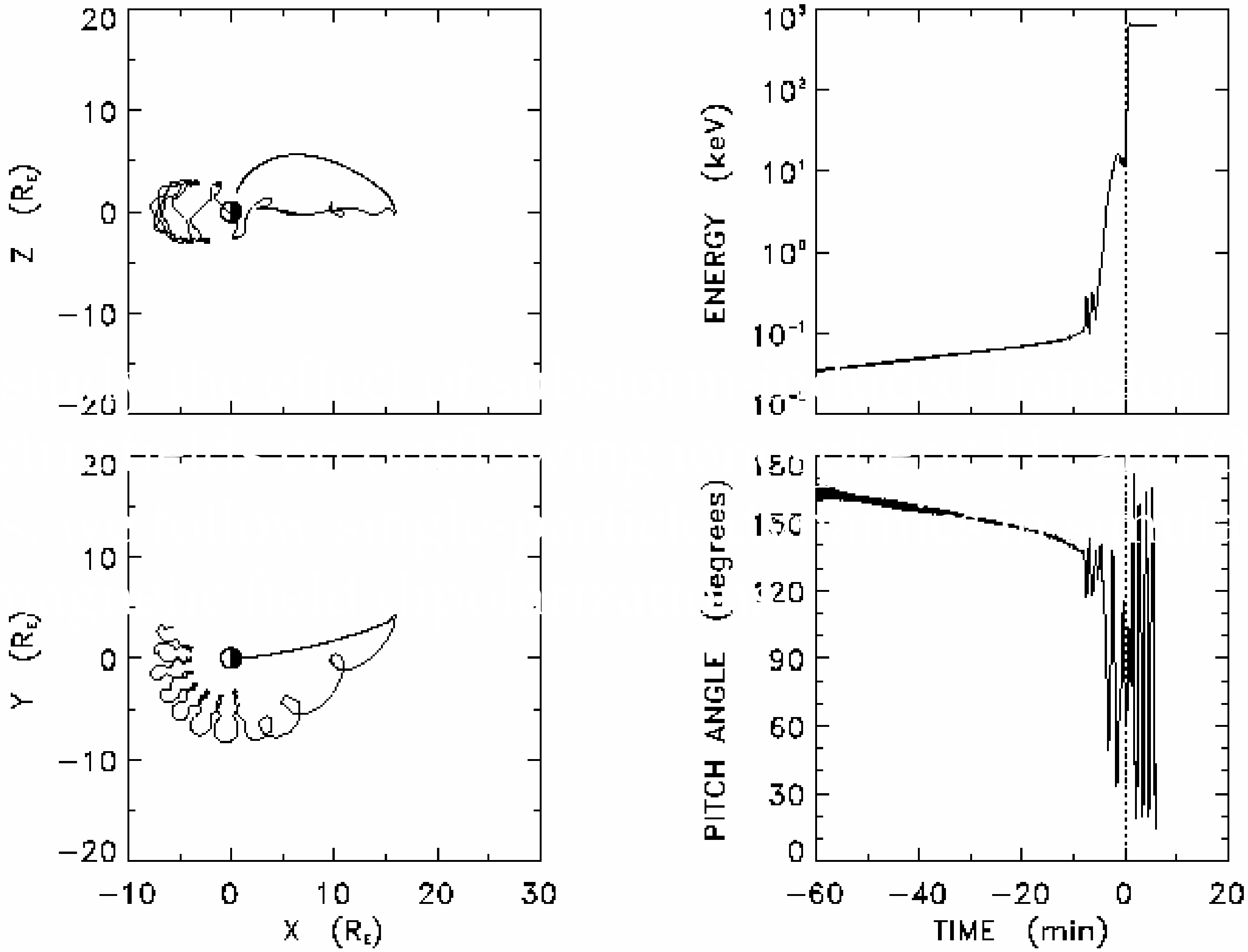
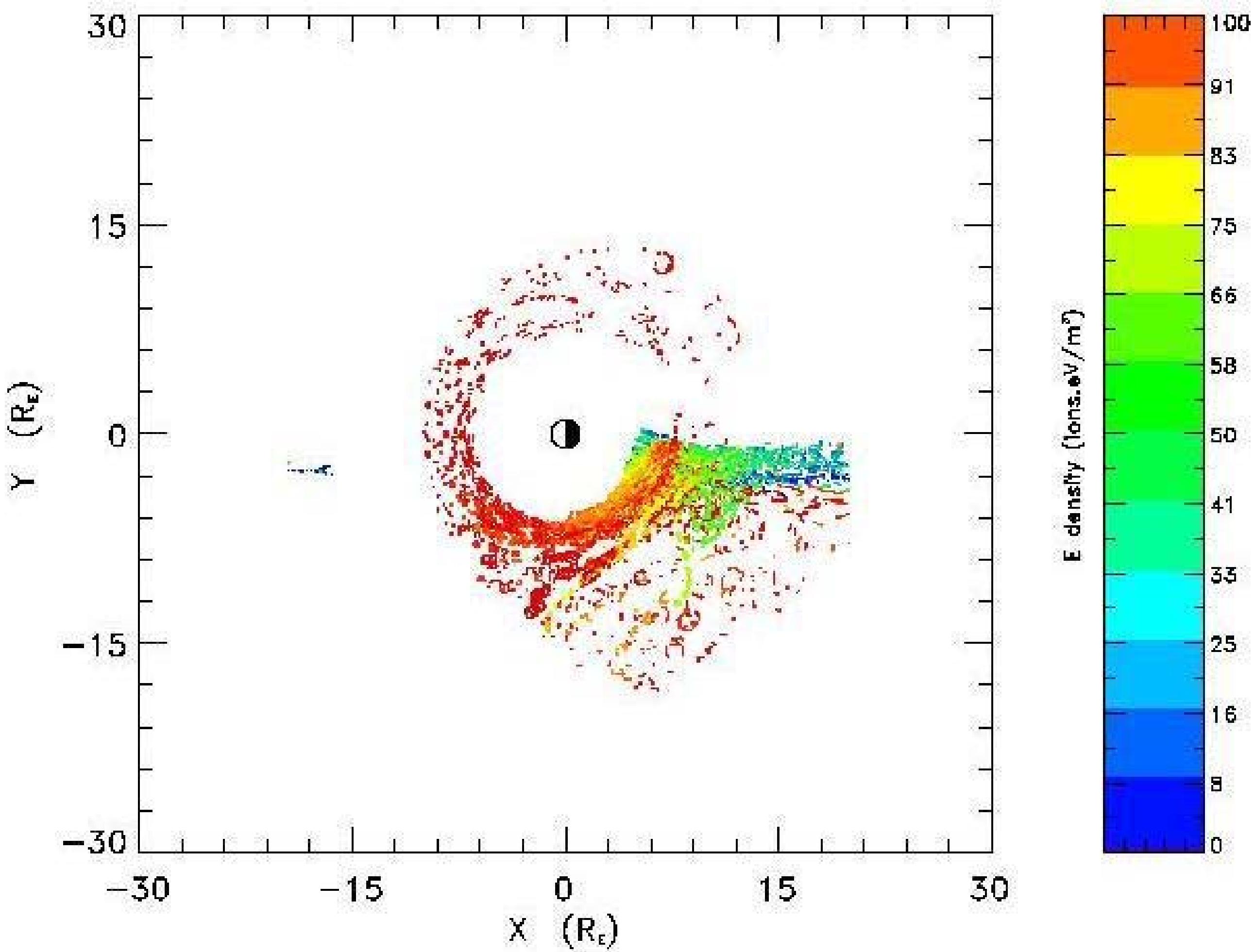


Fig. 10 of *Ganushkina et al.*, AnnGeo2005

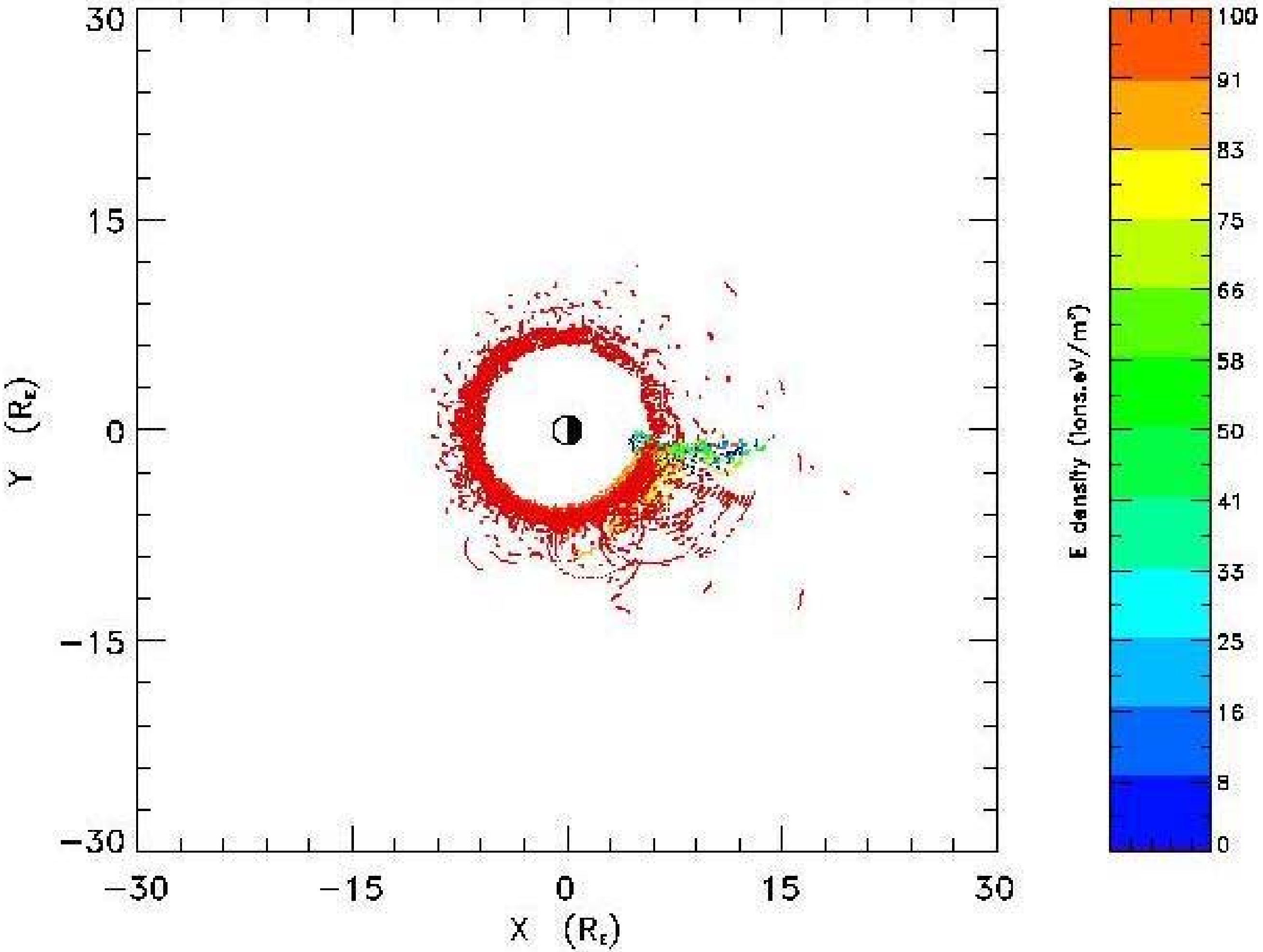
Ring Current Formation – Substorms



H^+ convection & substorm



O^+ convection & substorm



Ring Current Formation - Substorms

Substorm-induced transient electric fields clearly contribute to particle acceleration

Ring Current

- "Principles" and historical review
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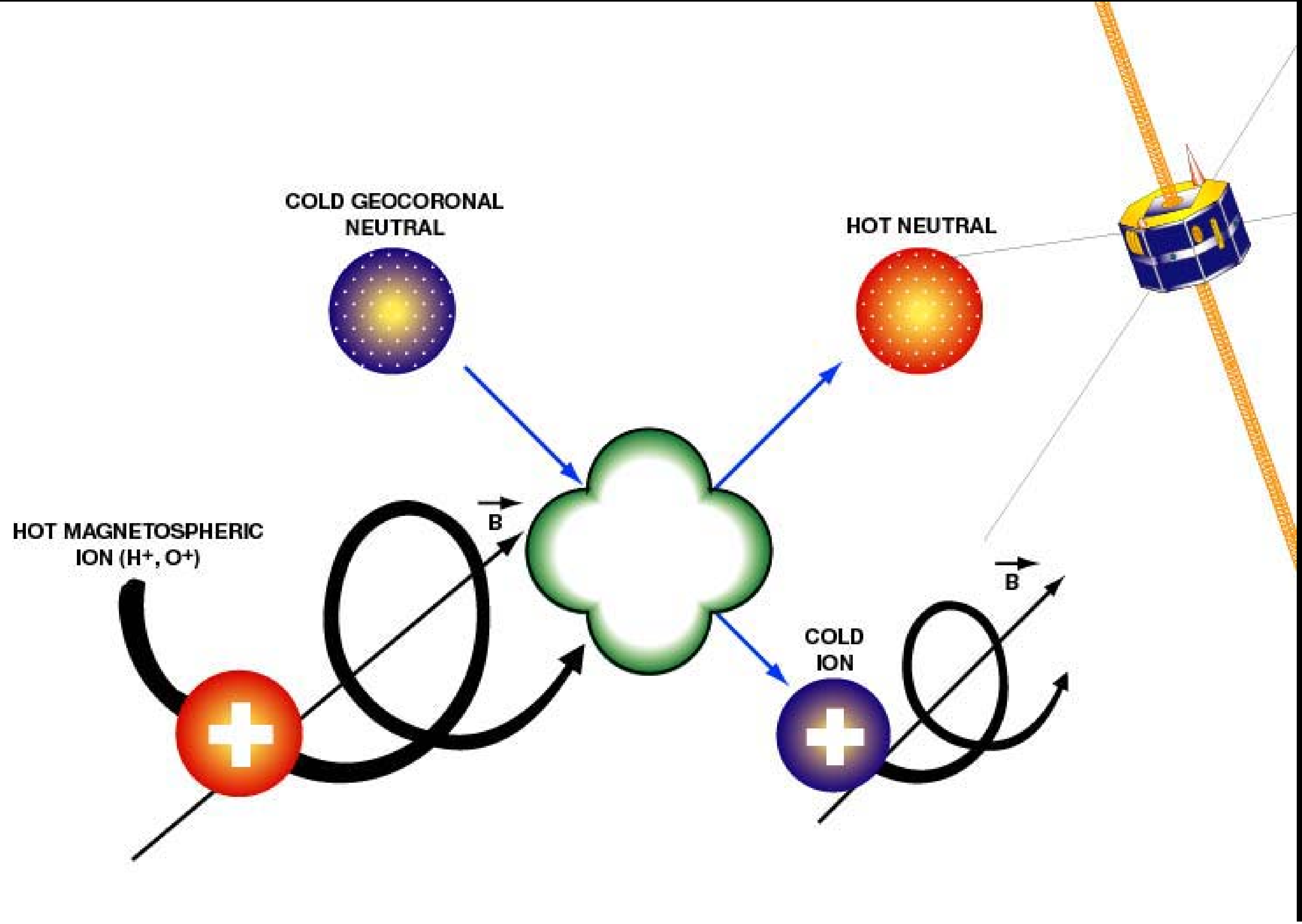
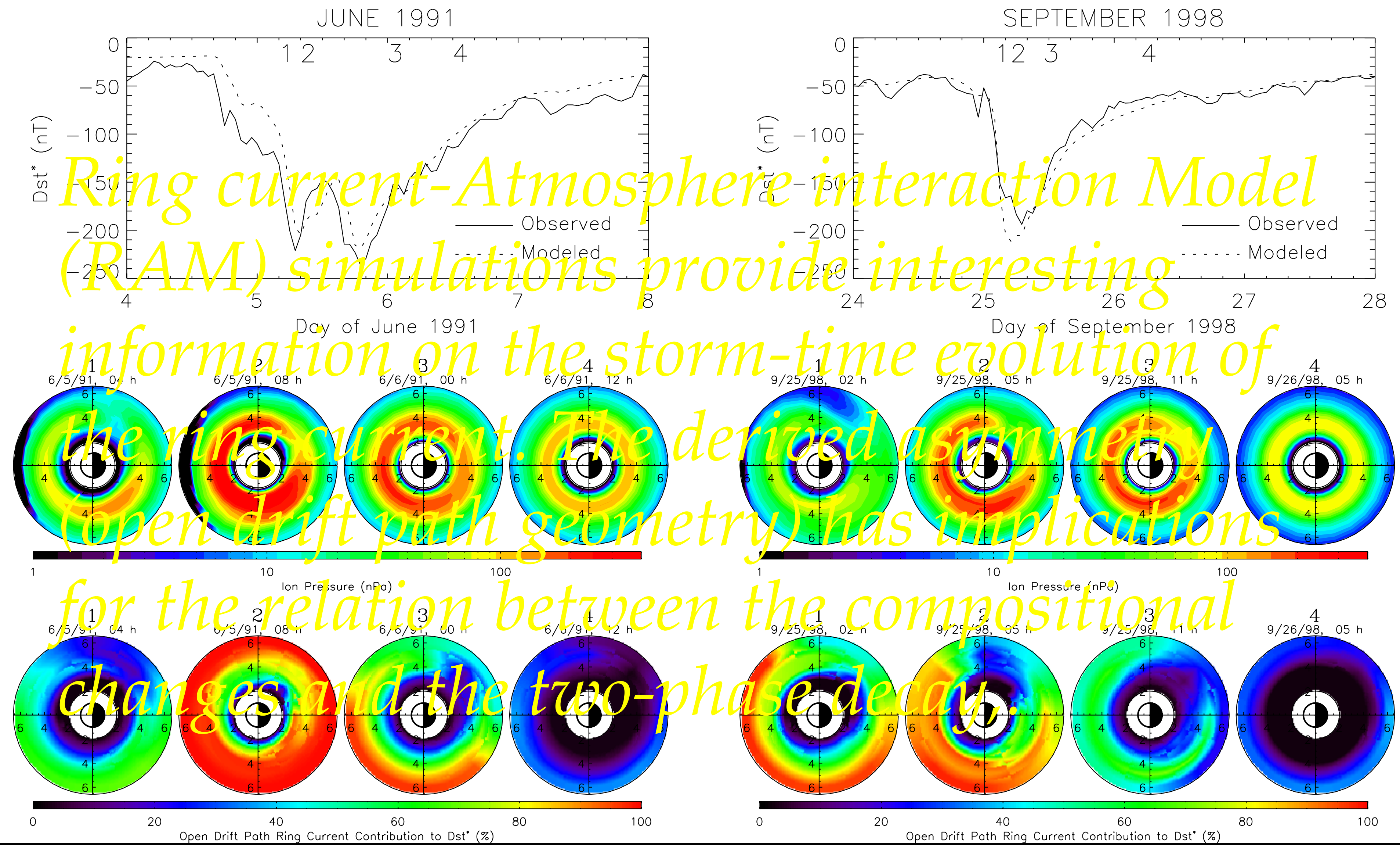
- RC formation: role of substorms
- **Dynamic evolution & decay**

Charge Exchange Process



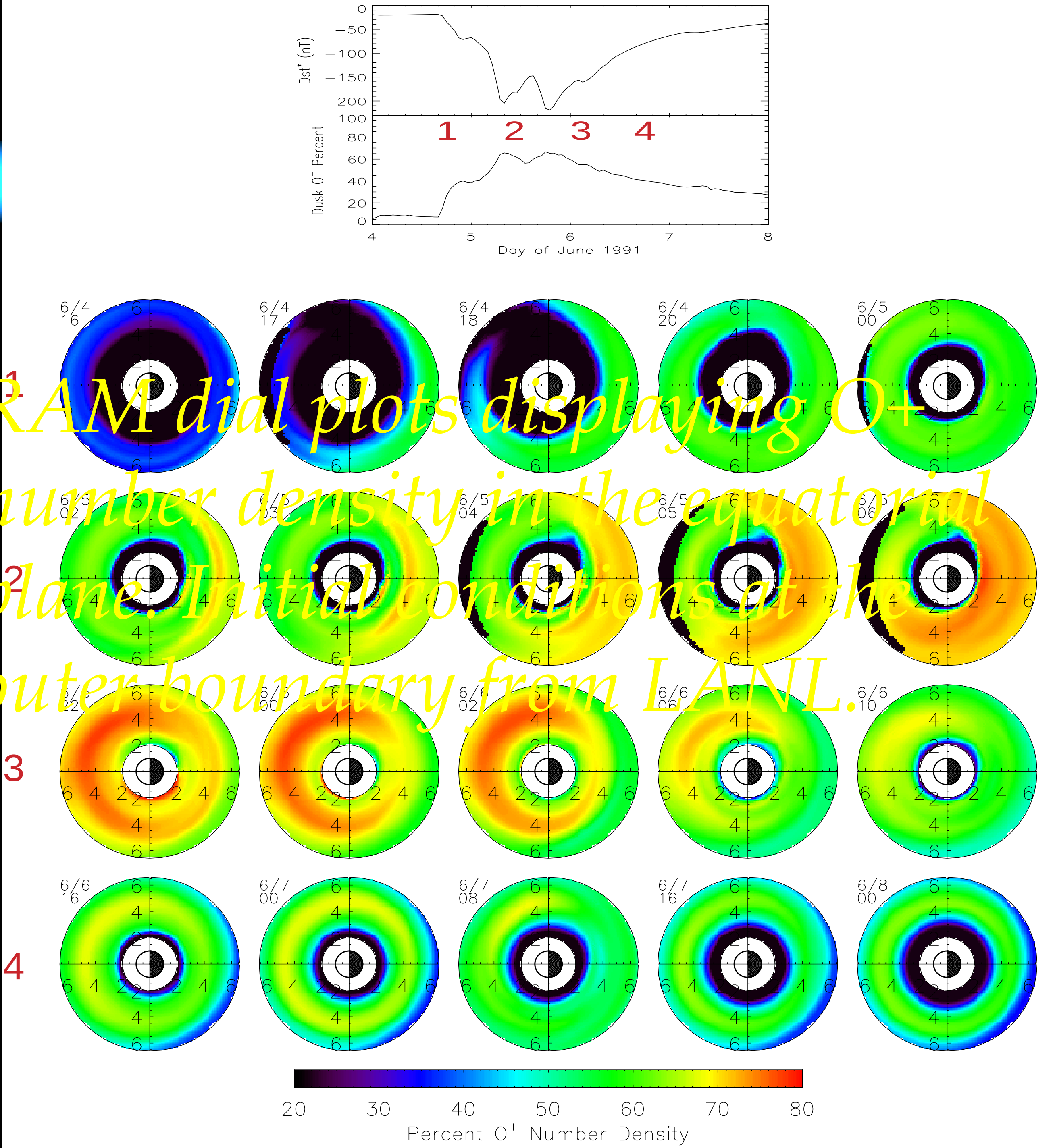
Dynamic evolution



Ring current-Atmosphere interaction Model (RAM) simulations provide interesting information on the storm-time evolution of the ring current. The derived asymmetry (open drift path geometry) has implications for the relation between the compositional changes and the two-phase decay.

Ring current asymmetry: Fig. 6 of Daglis et al. JGR2003

RAM dial plots displaying O+ number density in the equatorial plane. Initial conditions at the outer boundary from LANL.



Summary

- **The ionosphere is an "increasingly important" source and modulator**
- **IMF not the sole ruler: Plasma sheet density, ionospheric outflow, substorm occurrence, all have their role in storm development.**
- **Substorms act catalytically: the accelerate ions to high(er) energies / they preferentially accelerate O+ ions.**

Summary (2)

- Ring current is not symmetric (at max)
- Charge exchange is the major decay mechanism, but not so at storm maximum (convective drift loss)


The End