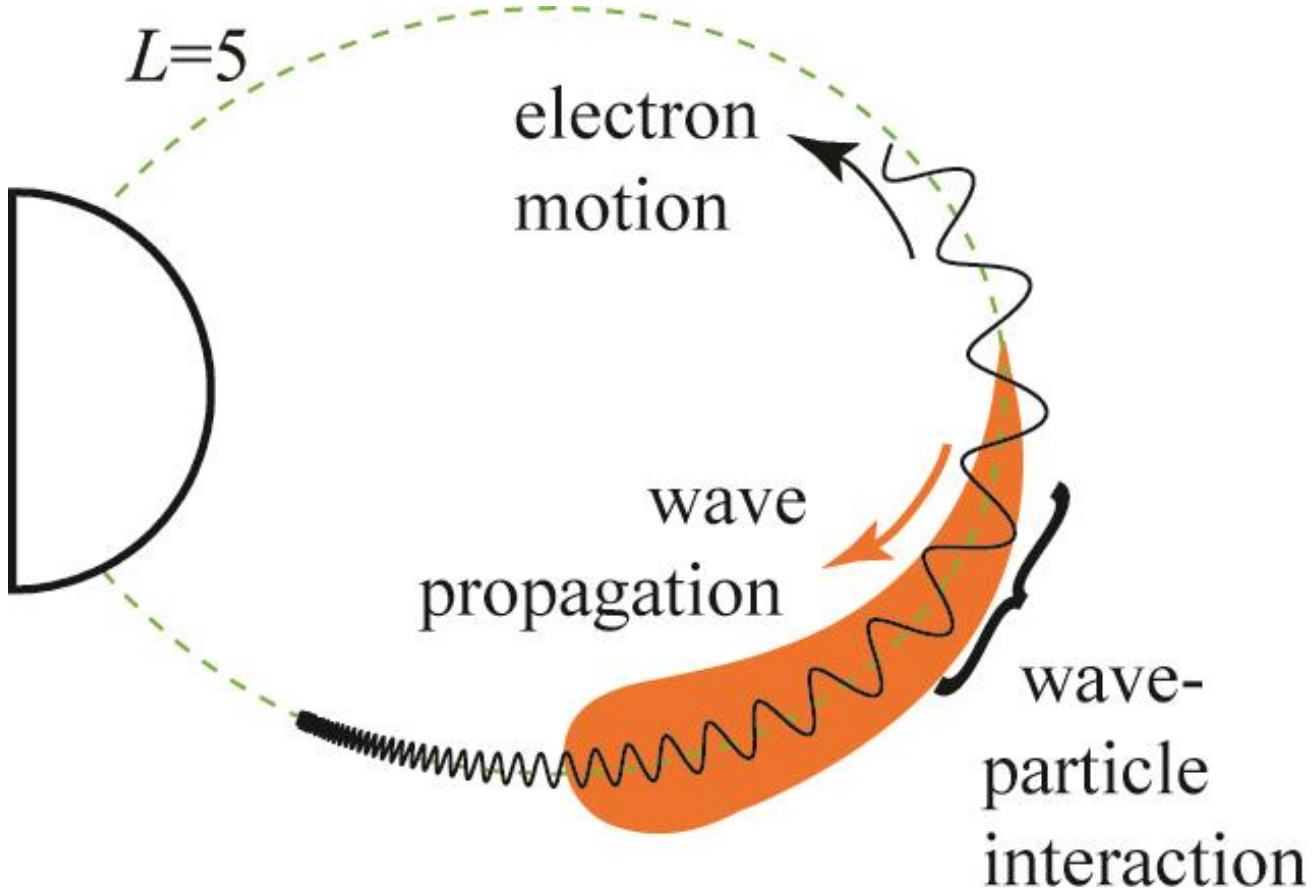
Space Physics Master's Course
Lecture 6
Sun-Earth Connection and Space Magnetic Storms

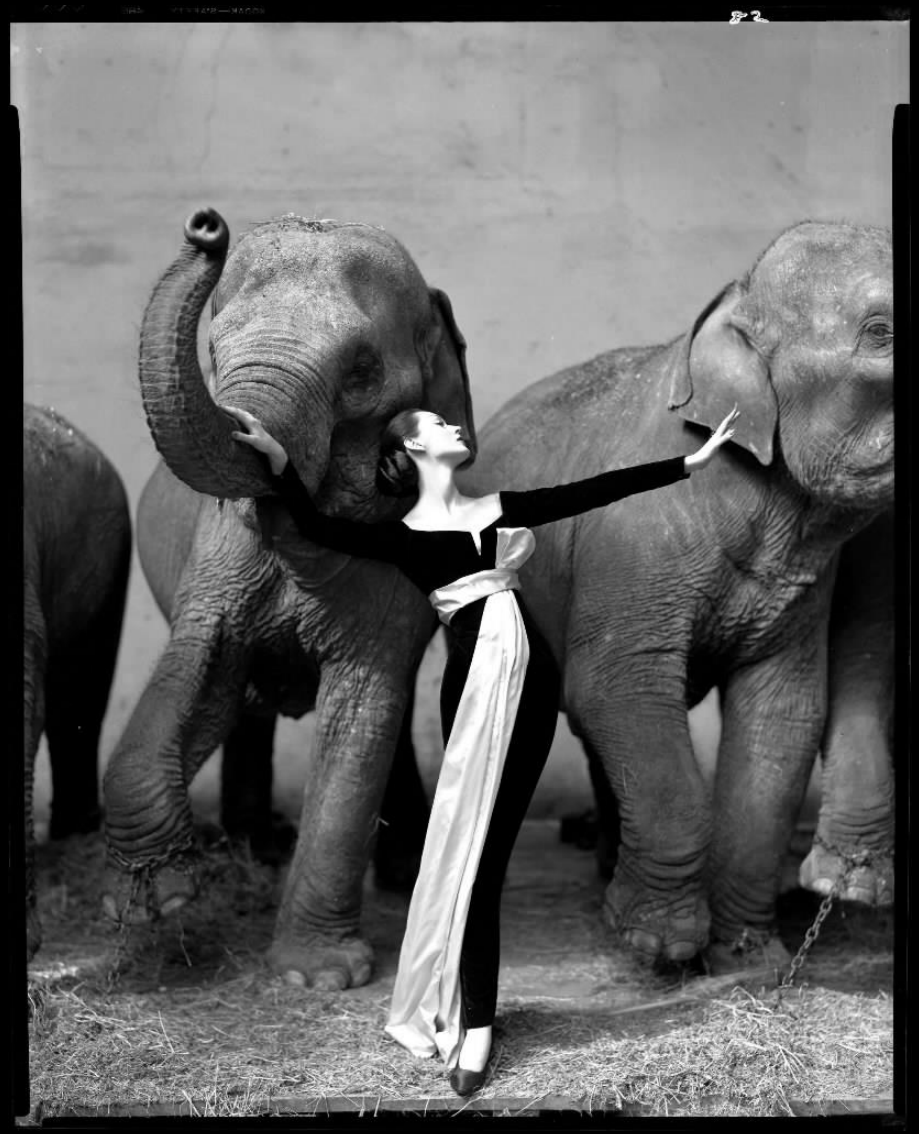


Richard Avedon:
Dovima and
the Elephants

Elephant foot: 6×10^5 Pa

Stiletto heel: 10^7 Pa

Dovima with the Elephants, Cirque d' Hiver, Paris;
by Richard Avedon, 1955
πολύ "ψαγμένη" φωτογραφία!



Dovima with the Elephants, Cirque d' Hiver, Paris;
by Richard Avedon, 1955
πολύ "ψαγμένη" φωτογραφία!

"Ricercar" was the original name for the musical form now known as "fugue". By Bach's time, the word "fugue" (or *fuga*, in Latin and Italian) had become standard, but the term "ricercar" had survived, and now designated an erudite kind of fugue, perhaps too austerely intellectual for the common ear. A similar usage survives in English today: **the word "recherché" means, literally, "sought out", but carries the same kind of implication, namely of esoteric or high-brow cleverness**. Δηλαδή "ψαγμένος".

Douglas R. Hofstadter
[Gödel, Escher, Bach: An eternal golden braid, 1979]

When you change the way you look at things, the things you look at change.

Max Planck
German theoretical physicist, discovered energy quanta, Nobel Prize in Physics 1918

Example: Sources of geospace plasma

Recommended Reading

Διαστημική Φυσική (Δαγκλής, Κατσαβριάς, Γεωργίου, Σέργης)

Κεφάλαια 6-8

(https://repository.kallipos.gr/handle/11419/11507)

Gombosi: Magnetic Storms and Magnetospheric Substorms

Daglis: Geospace Magnetic Storms (assignment 2 – θα σταλεί)

Reeves and Daglis: Storms and radiation belts

https://eclass.uoa.gr/modules/document/file.php/PHYS367/Βιβλιογραφία/Chapter%203%20Reeves%20and%20Daglis.pdf

Εργασία 1

Παράδοση:

Παρασκευή 7 Νοεμβρίου 11μμ

Παρουσίαση:

Δευτέρα 10 Νοεμβρίου, περίπου 30 λεπτά η κάθε ομάδα

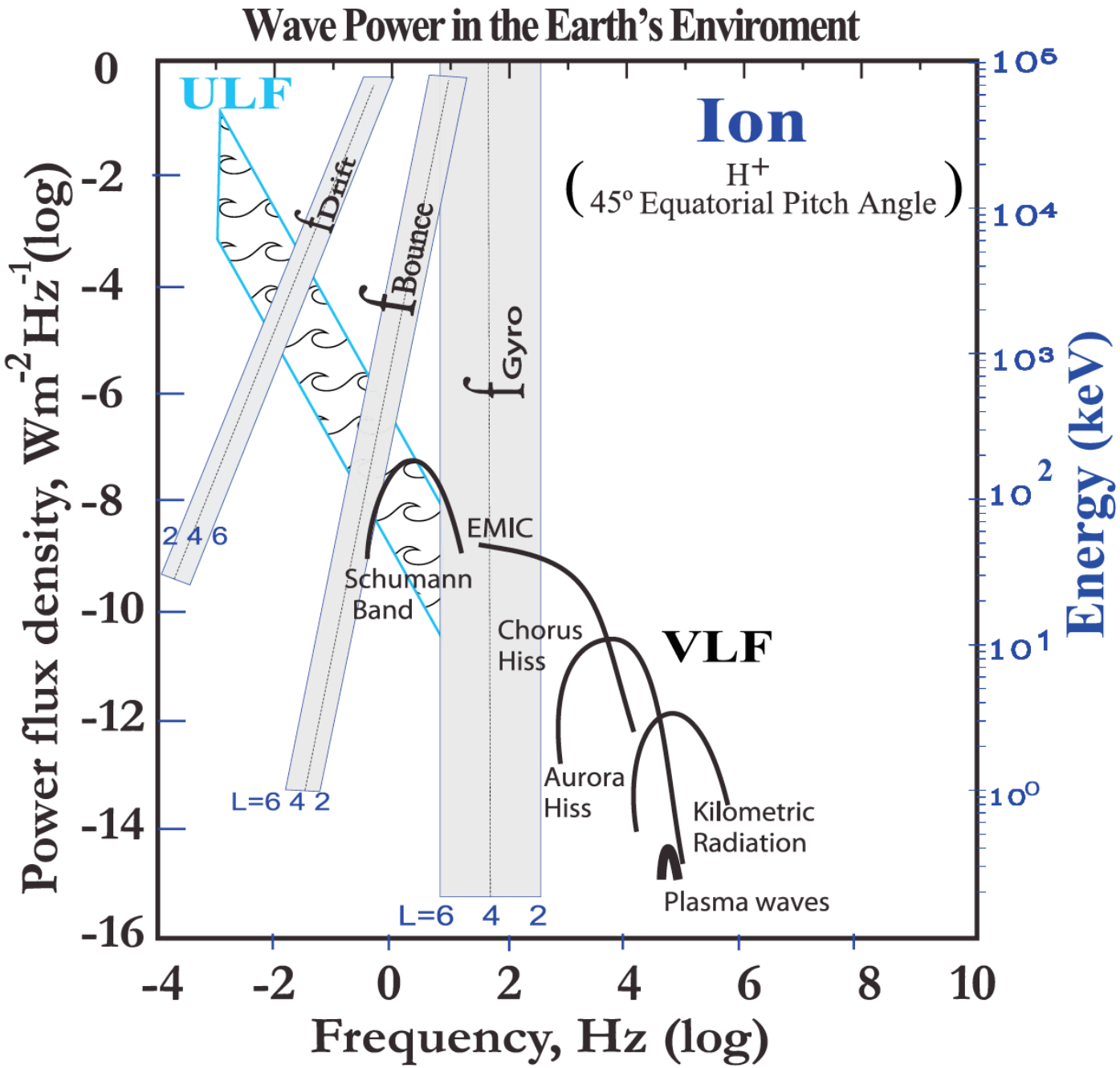
Εργασία 2

Παράδοση:

Παρασκευή 21 Νοεμβρίου 11μμ

Παρουσίαση:

Δευτέρα 24 Νοεμβρίου, περίπου 30 λεπτά η κάθε ομάδα


Wave Power in the Earth's Enviroment
ULF
Ion
H+
45° Equatorial Pitch Angle
fDrift
fBounce
fGyro
2 4 6
EMIC
Schumann
Band
Chorus
Hiss
VLF
Aurora
Hiss
Kilometric
Radiation
Plasma waves
L=6 4 2
L=6 4 2
Power flux density, Wm-2Hz-1(log)
Frequency, Hz (log)
Energy (keV)
0
-2
-4
-6
-8
-10
-12
-14
-16
-4
-2
0
2
4
6
8
10
10^6
10^4
10^3
10^2
10^1
10^0

Magnetospheric Plasma Sources

Mercury:	solar wind and sputtering of surface material, e.g. sodium
Earth:	solar wind and ionosphere
Jupiter:	solar wind and volcanic activity of the moon Io
Saturn:	solar wind, atmosphere of moon Titan, sputtering at surfaces of icy moons and rings
Uranus:	polar ionosphere, minor solar wind contribution
Neptune:	ionosphere, moon Triton

Magnetospheric Control Parameters

- Solar wind dynamic pressure

- B_Z component of the interplanetary magnetic field

- Planetary magnetic field

- Plasma sources and mass density

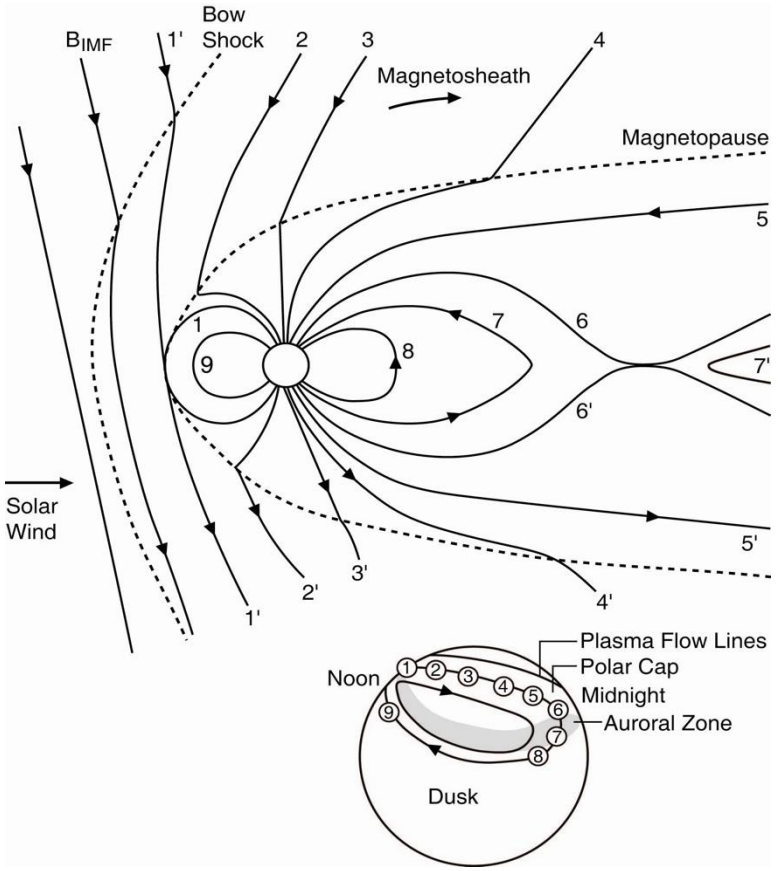
- Ionospheric conductivity

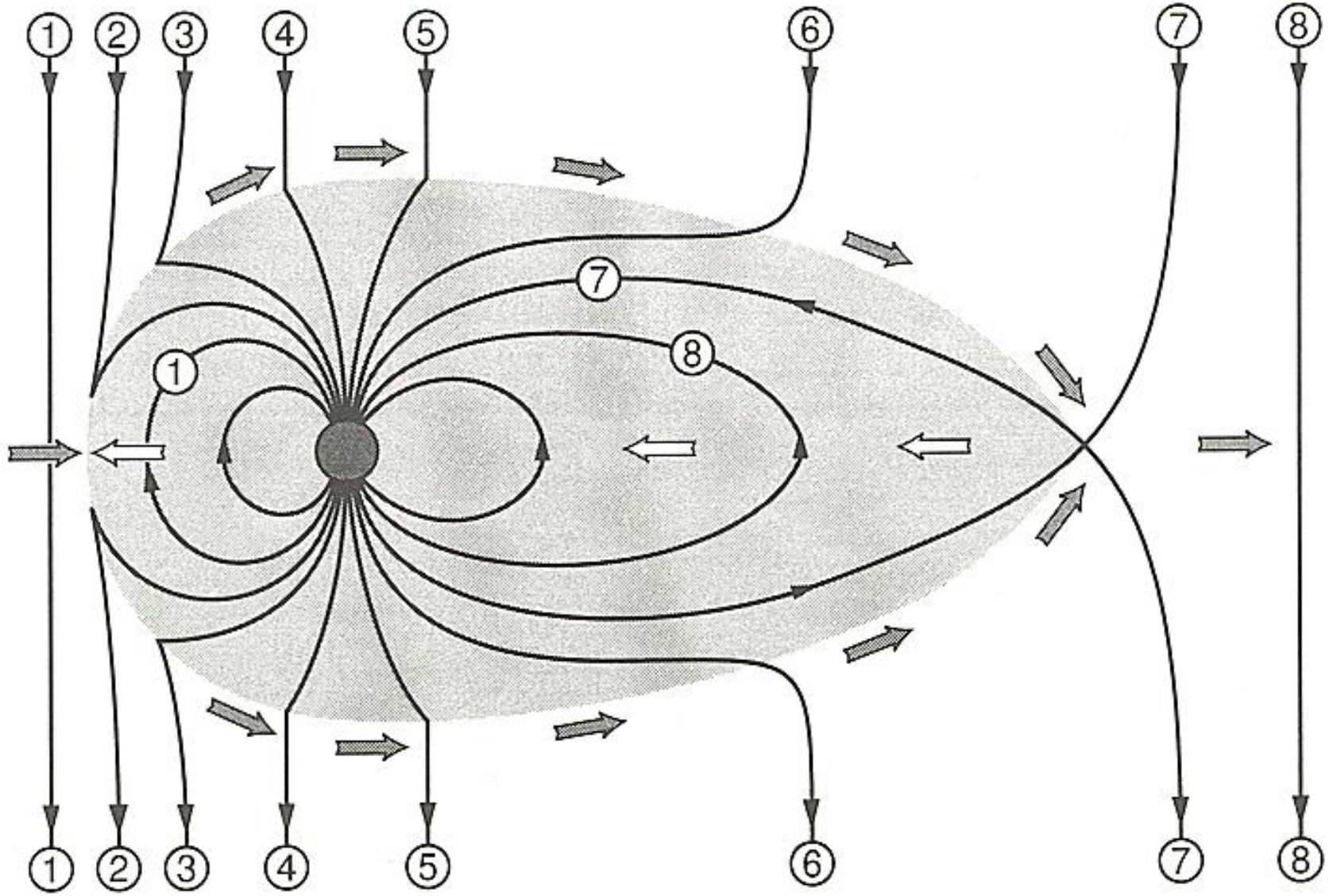
- Magnetospheric scale

Energy transfer and storage

Given that **reconnection** links the solar and terrestrial B fields, the **energy transfer** from the solar wind to the tail occurs quite naturally.

On the night-side, the field lines in the tail stretch and the solar wind plasma slows down. Hence, energy is removed from the flow and stored in the magnetic field in the tail. The rate of energization can be calculated from the Poynting vector integrated over the surface of the tail. The magnetic energy, flux and field strength of the tail increase.

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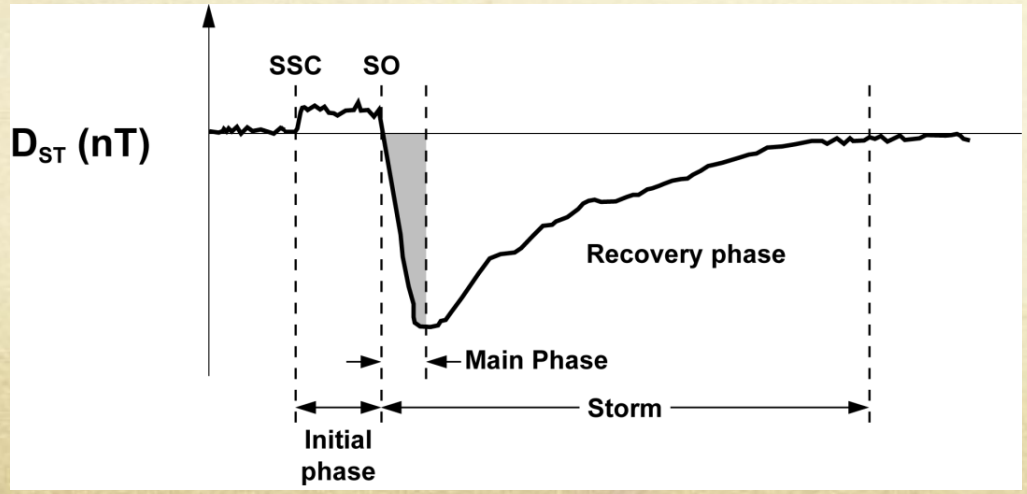
Μεταφορά ισχύος
(δηλαδή ρυθμός μεταφοράς ενέργειας)
ανάλογη του:

$P_{dyn}\ v_{sw}\ B_s$

Space Storms

- Historically defined (and identified) as prolonged world-wide depressions of H-component of geomagnetic field
- Associated with aurora and solar eruptions
- Now recognized as the most complex, multi-faceted dynamic phenomenon in geospace



Space Storms

Not to be confused with Solar Storms,

(aka Solar Radiation Storms)

which are episodes of intense acceleration

of solar particles to very high energies

(Solar Energetic Particles – SEPs)

by solar flares and/or CMEs.

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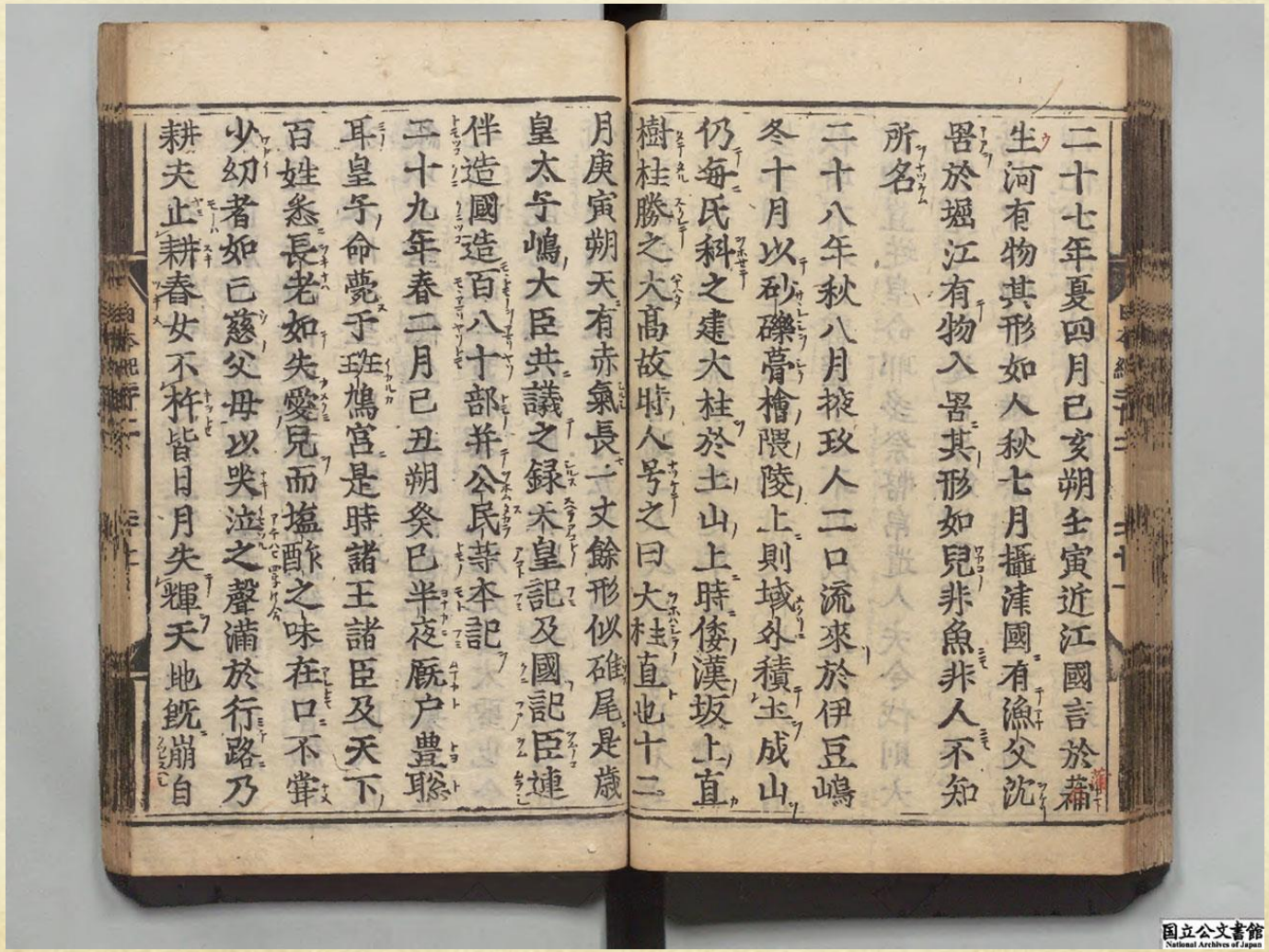
Solar Storms and Space Storms **are not identical!**

Solar Storms **do not cause** Space Storms!

Aurora in *Rikkokushi* - chronicles of ancient Japan



620 AD, Hayakawa+, Publ. Astron. Soc. Jpn 2017

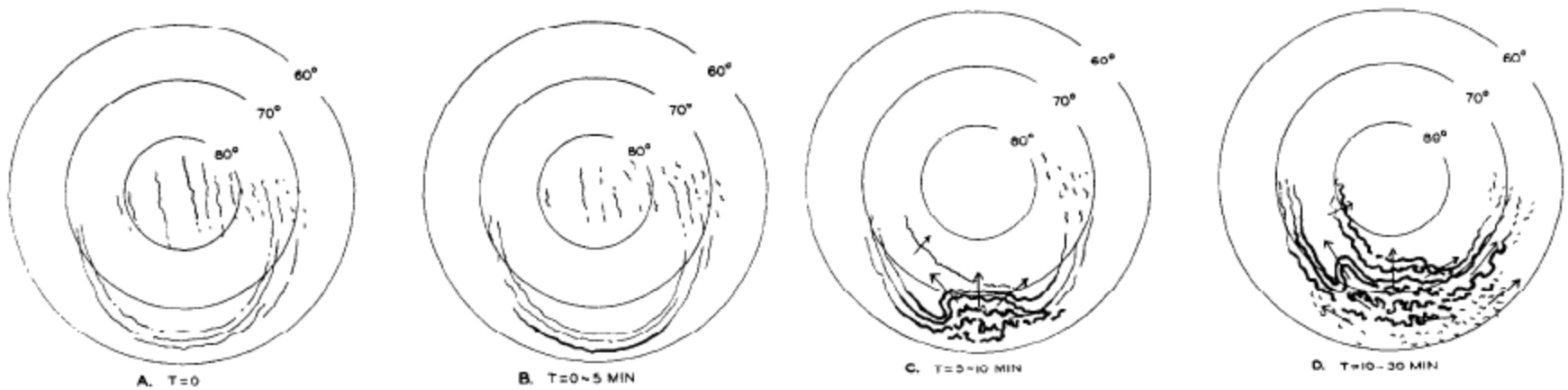
Planet. Space Sci. 1964. Vol. 12, pp. 273 to 282. Pergamon Press Ltd. Printed in Northern Ireland

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.



Aurora – The magnificent northern lights

Ioannis Daglis* and Syun-Ichi Akasofu**

*Research Director, National Observatory of Athens, Athens, Greece

**Professor, University of Alaska, Director, International Arctic Research Center, Fairbanks, USA

Figure 1: Auroral bands with rays, Alaska. © Jan Curtis

Figure 2: Aurora in Manitoba, Canada. © Warren Justice

Daglis and Akasofu, CSEG 2004

Aurora in Greece

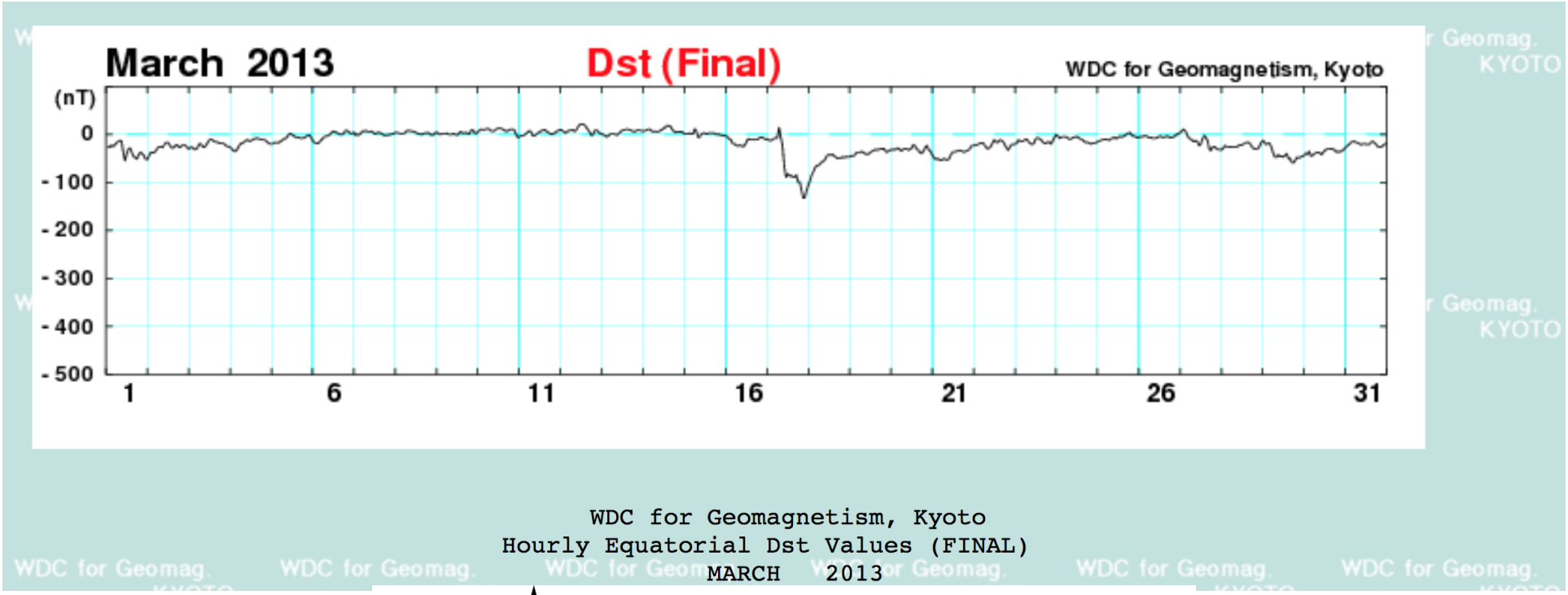
Aurora in Greece

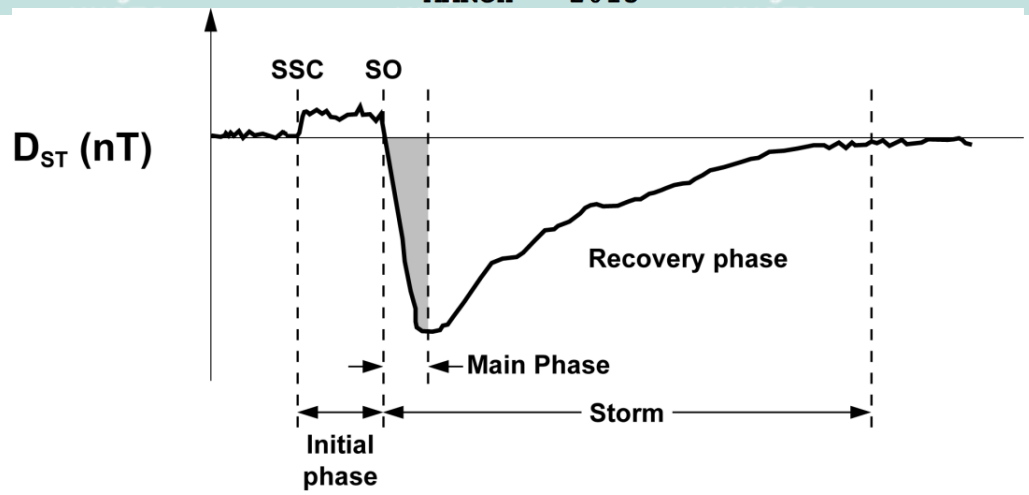
Aurora in Japan

2003年10月30日　4:24（JST）　20mm　F2.8　ISO400　露出時間：5分　キャノンEOS55

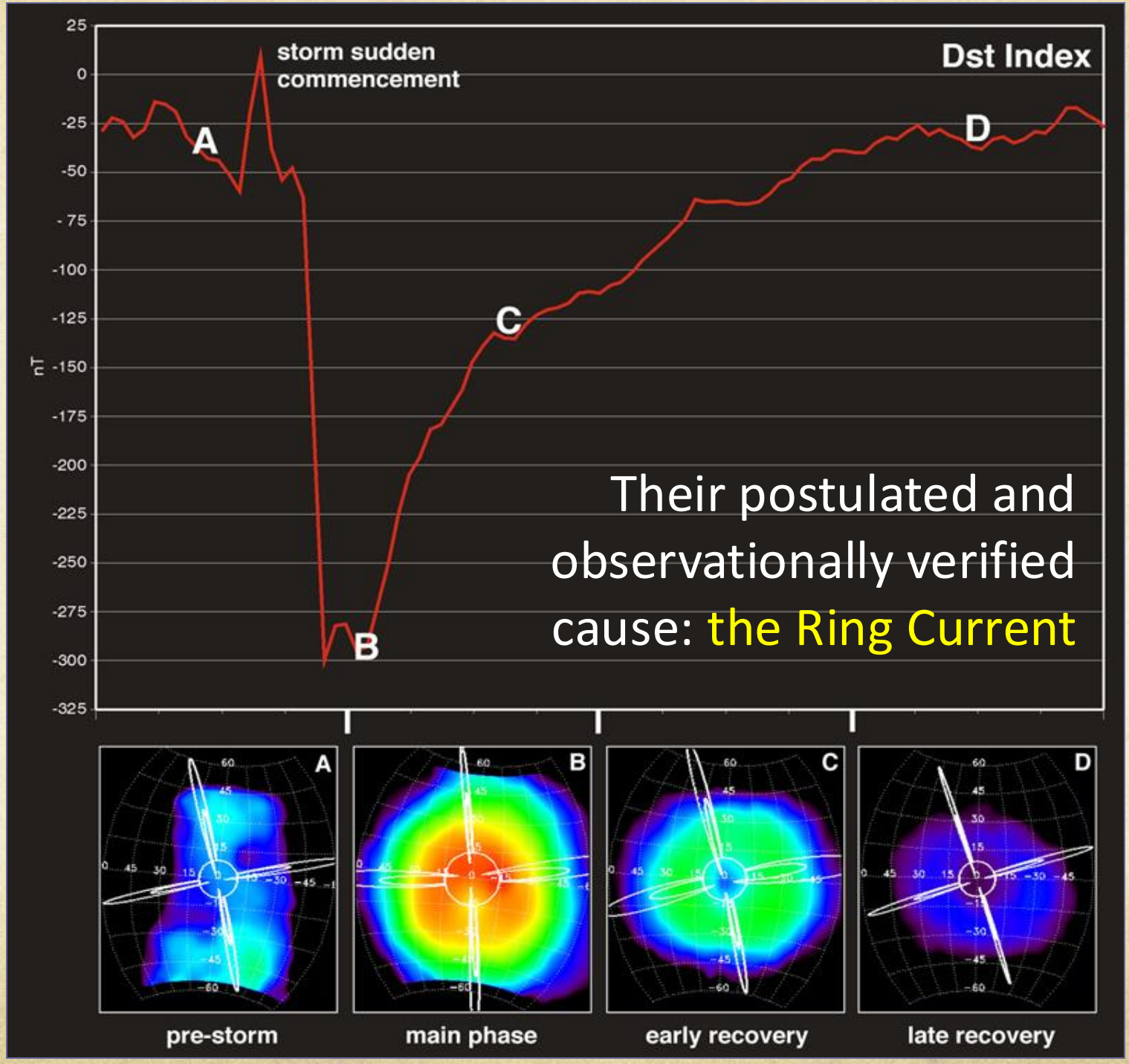
りくべつ宇宙地球科学館（銀河の森天文台）

Kyoto Word Data Center for Geomagnetism



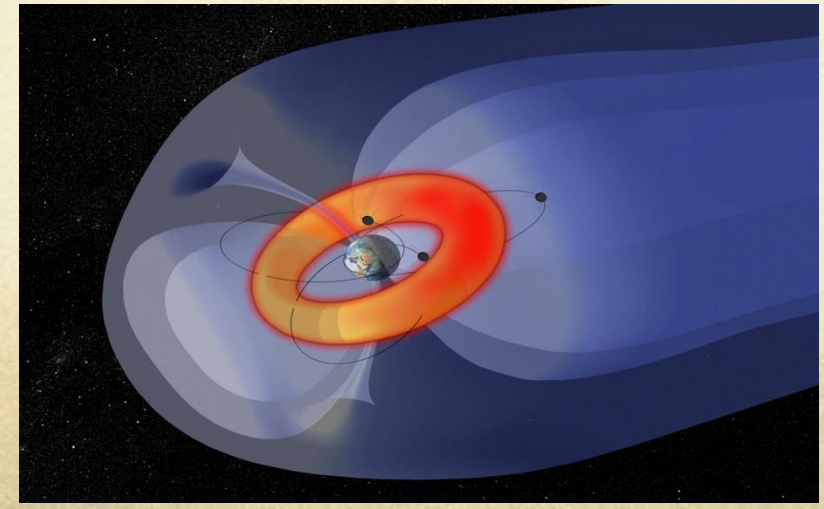


Magnetic Storms

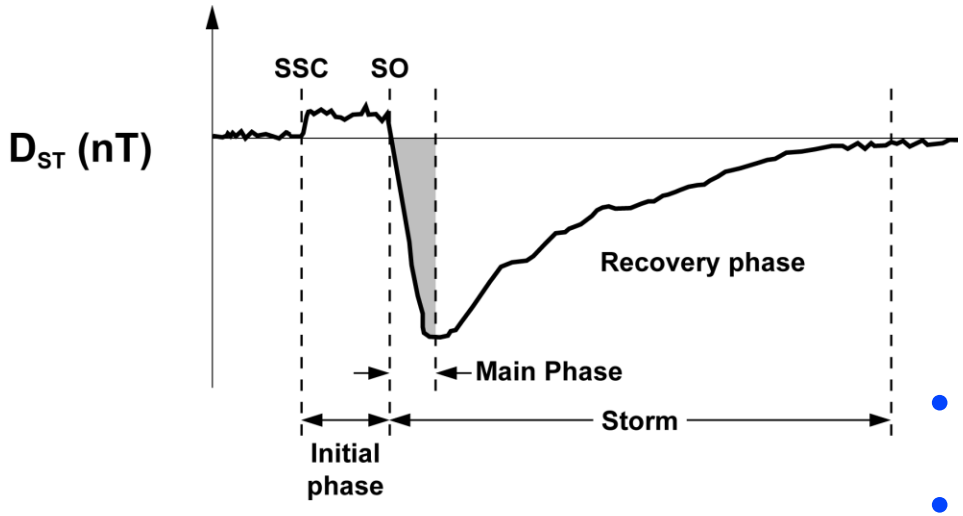


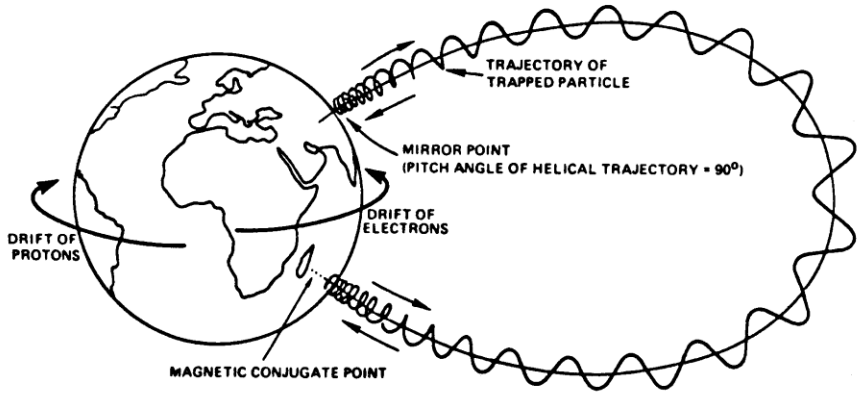
Ring Current

- Carried mainly by ions (H^+, O^+, N^+, He^{++}, He^+) in the energy range ~1 keV to a few 100s keV
- Bulk of energy within 50-100 keV
- Spatial extent: ~2-8 R_E (geocentric)
- Maximum intensity at ~3-5 R_E (geocentric)



Geomagnetic Storm: Ring Current Evolution





- **Composition: e^-, H^+, He^+, O^+, N^+, He^{++}**
- **Energy Range: ~ 1 keV < E < 300 keV**
- **Location: ~ 2 < L < 8**
- **Energy Density: ~ 10 - 1000 keV/cm^3**

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*, 1972

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Ring current

One Ring to rule them All

One Ring to rule them All

The ring current was the first space particle population theoretically predicted, in an effort to explain the occurrence of magnetic storms.

The radiation belts were the first space particle population to be actually discovered.

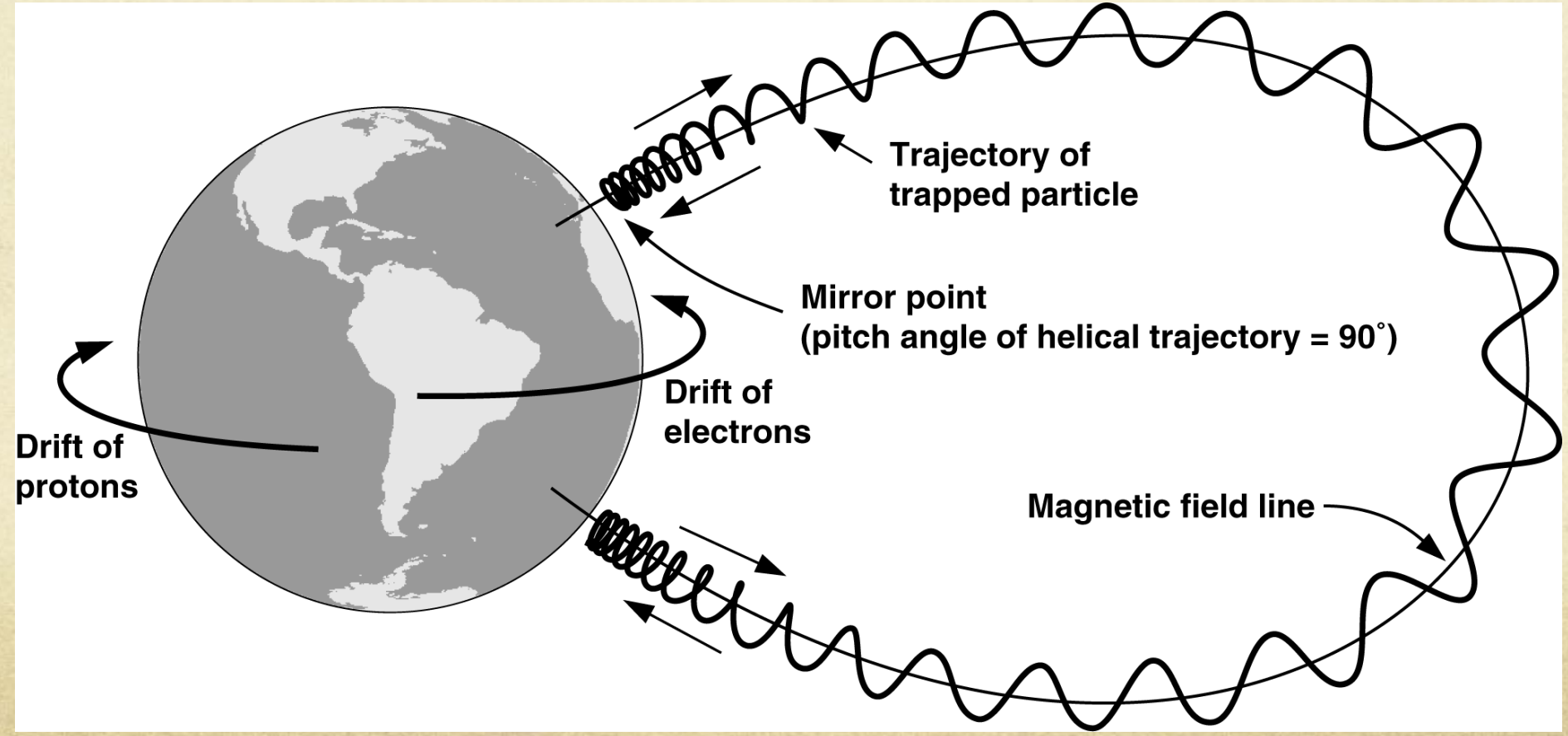
Their main difference is their energy level.

Van Allen Radiation Belts

Same principle as RC:

a combination of gyro, bounce and drift motions

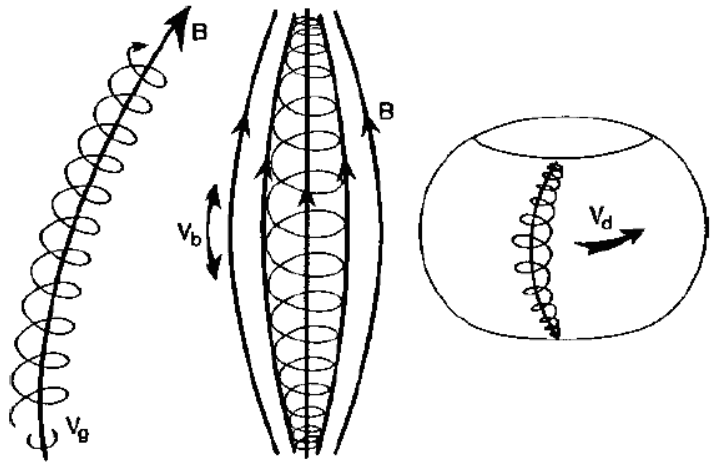
corresponding to three invariants



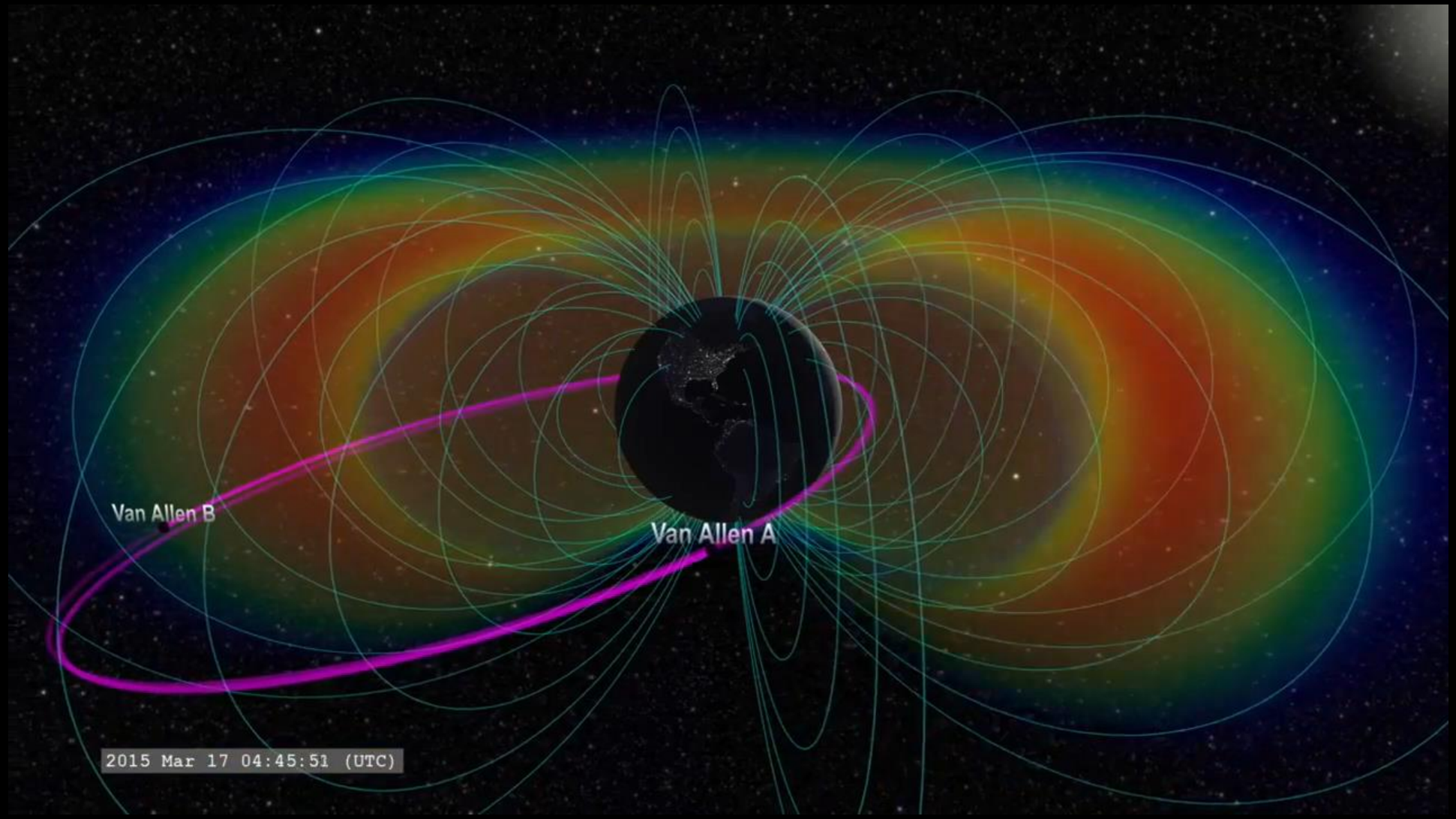
Periodic motion

- Energetic particles undergo three types of periodic motion:
  - They gyrate around the magnetic field
  - They bounce between the mirror points
  - They drift around the Earth
- Associated adiabatic invariant

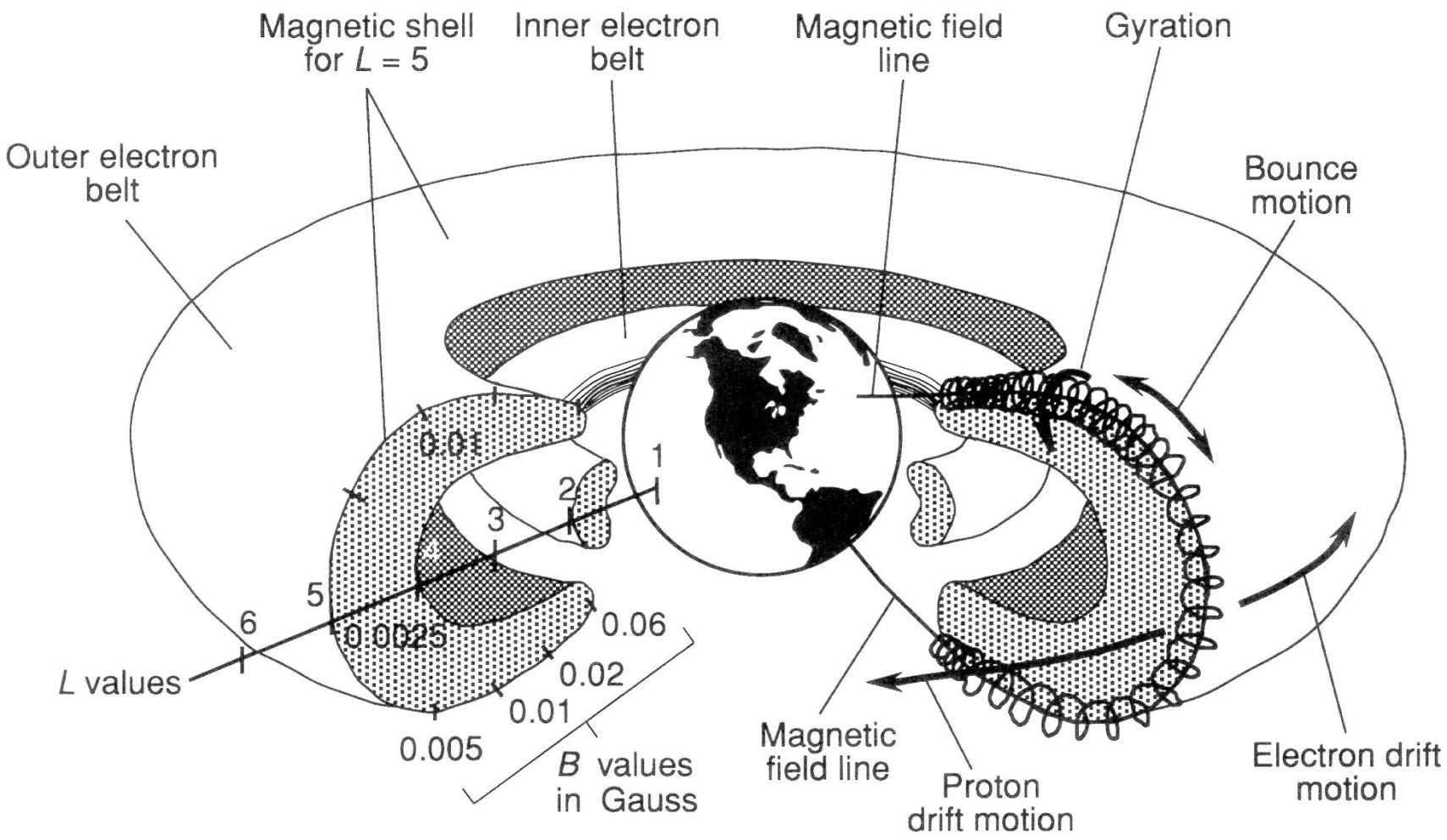
1 MeV electron, α = 45°, L = 4.5



	gyro motion	bounce motion	drift motion
f	10 kHz	3 Hz	1 mHz
T	0.1 ms	0.36 s	15 min
	$\mu = \frac{p_\perp^2}{2mB}$	$J = \int_{bounce} p_\parallel ds$	$\Phi = \int_{drift} BdS$


Van Allen B
Van Allen A
2015 Mar 17 04:45:51 (UTC)

Van Allen Belts



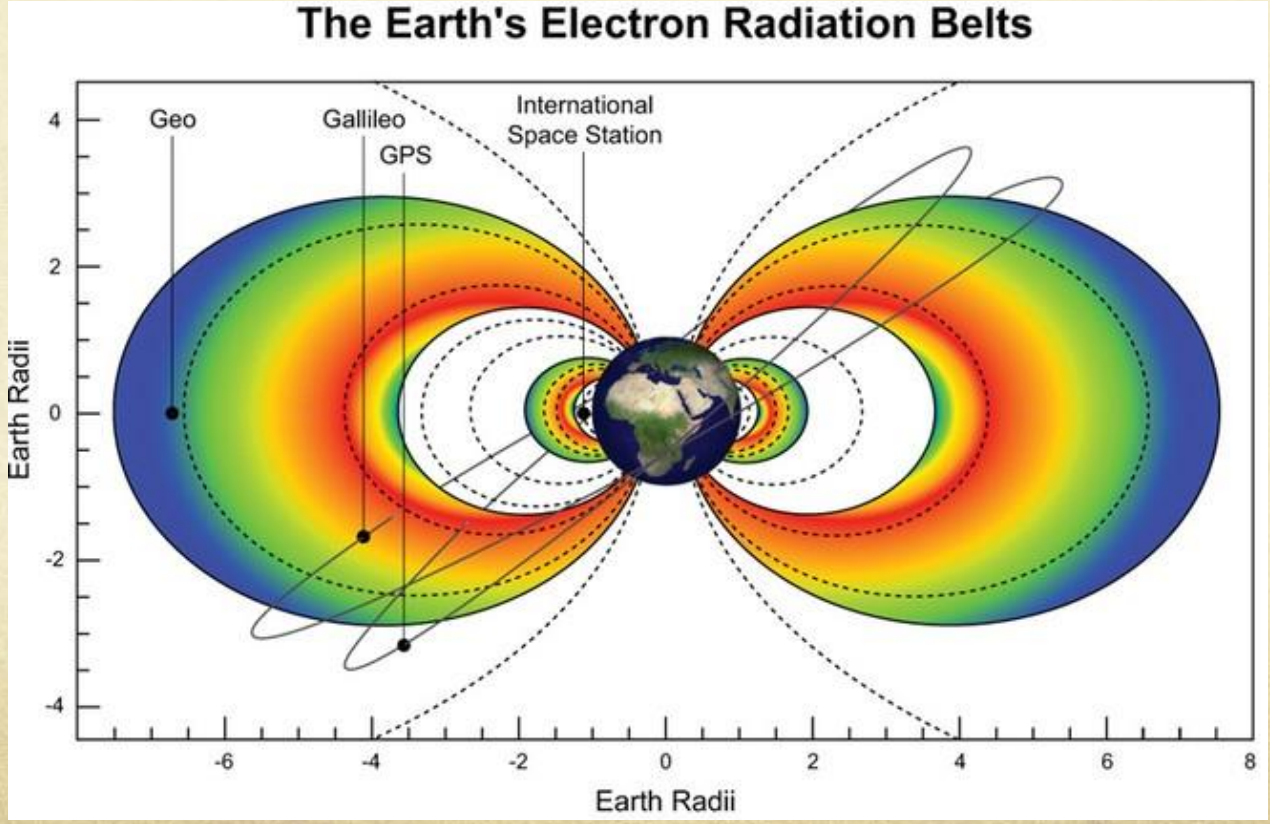
Mitchell [1994]

Van Allen Radiation Belts

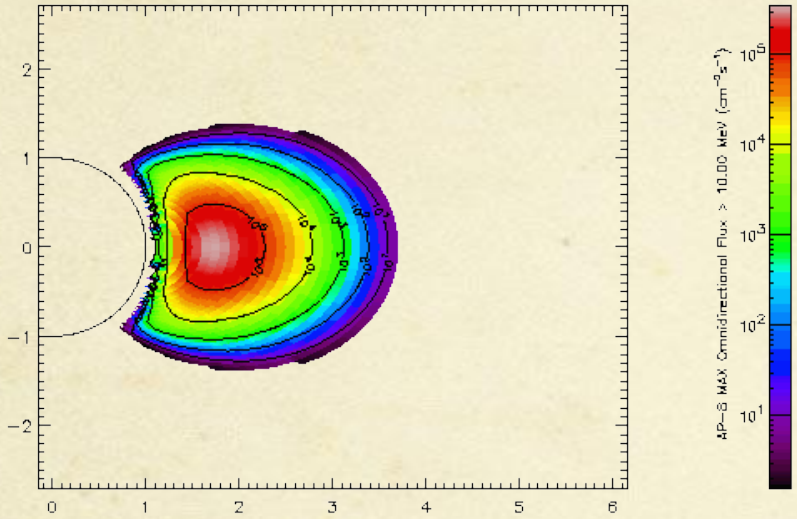
Distinguished by their (very) high energies:

100 keV – 10+ MeV (400 MeV)

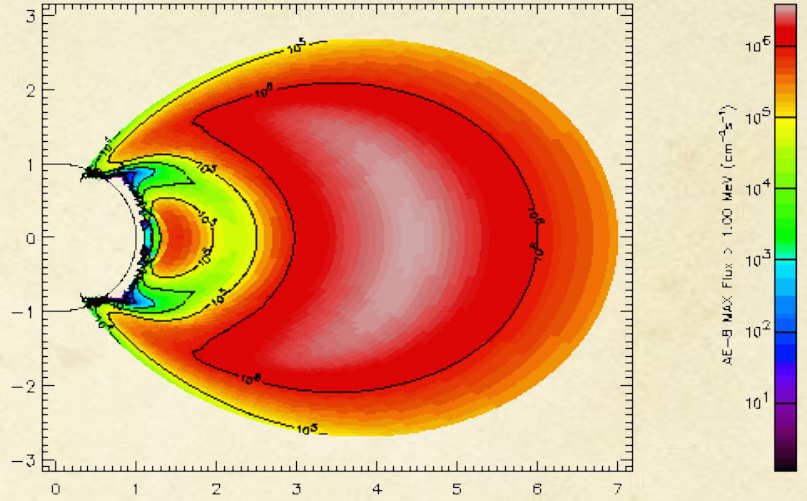
and posing considerable threat to space assets



Van Allen Radiation Belts



Integral proton flux > 10 MeV
AP8 static model



Integral electron flux >1 MeV
AE8 static model

Ions:

- mainly protons
- confined to the inner zone
- energies 100's keV < E < 400 MeV

Electrons:

- two distinct populations: inner & outer zone
- energies 100 keV < E < 20 MeV
- steep power law: $E^{-(5-8)}$

The first artificial radiation belt

Nicholas Christofilos, a Greek scientist who migrated in the US in 1953, had proposed in October 1957 that charged particles could be trapped around the Earth and that an artificial radiation belt, due to beta decay, could be created by exploding one or more small nuclear fission bombs at high altitude (~200 km)

The first artificial radiation belt

Christofilos' proposal evolved into Argus - the first active experiment in space, which was successfully performed in 1958

JOURNAL OF GEOPHYSICAL RESEARCH VOLUME 64, No. 8 August, 1959

The Argus Experiment*

N. C. CHRISTOFILOS

Lawrence Radiation Laboratory, University of California
Livermore, California

Abstract—A geophysical experiment on global scale was conducted last fall. Three small A-bombs were detonated beyond the atmosphere at a location in the south Atlantic. The purpose of the experiment was to study the trapping of the relativistic electrons (produced by the β-decay fission fragments) in the geomagnetic field. The released electrons are trapped by this field oscillating along the magnetic lines between two mirror points. In addition to this motion the electrons drift eastward, creating a thin electron shell around the earth. The lifetime and location of the thus-created global electron shell were measured by satellite- and rocket-borne instruments. Auroral luminescence was observed at the conjugate points. The electron shell exhibited remarkable stability during its lifetime. *No* motion of the shell or change in its thickness was detected.

This experiment was proposed by the writer a few weeks after the launching of the

The first artificial radiation belt

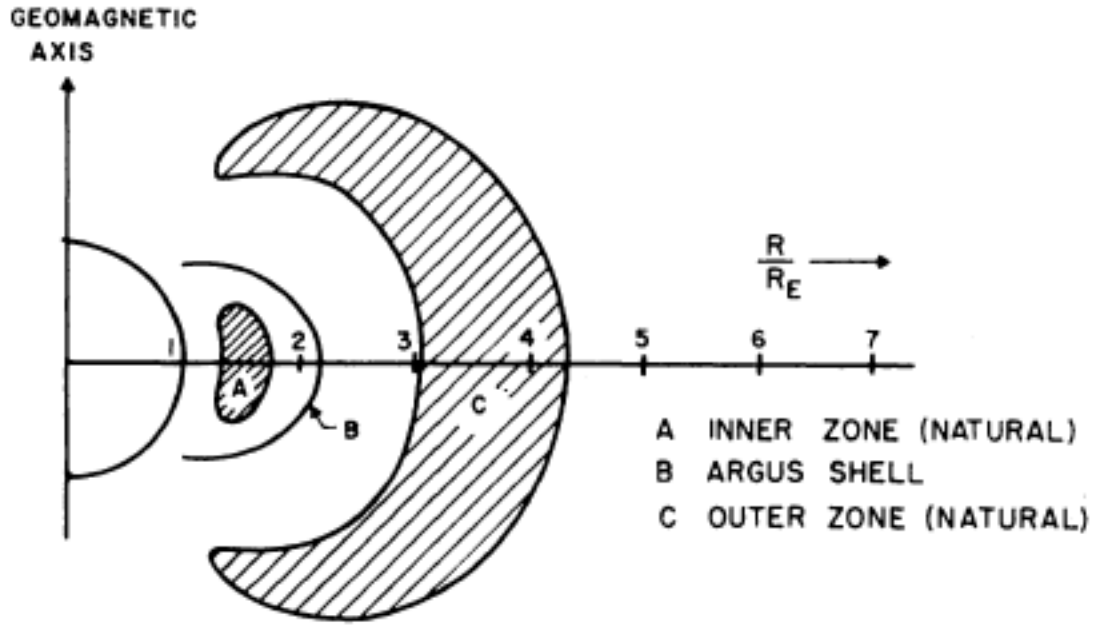
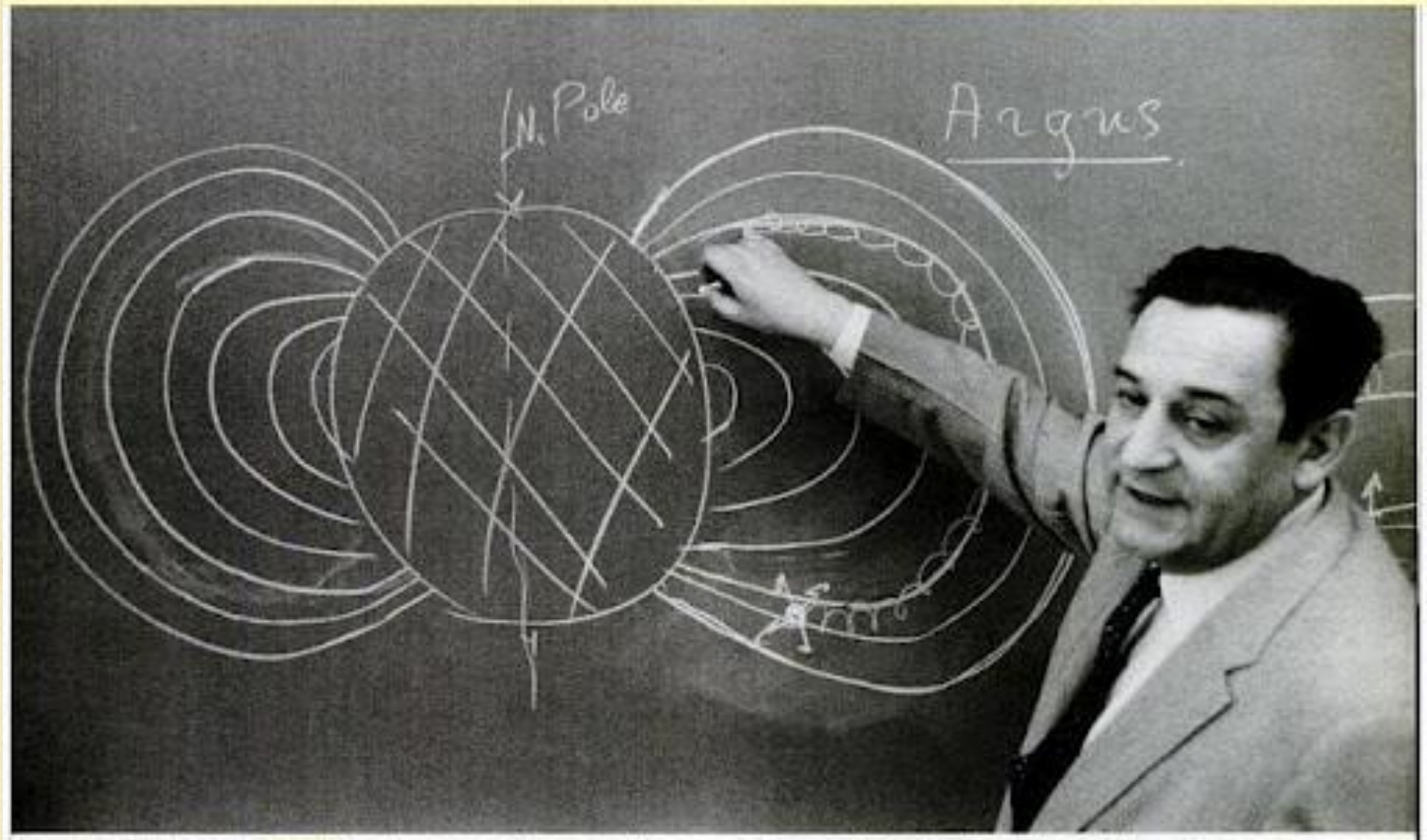


FIG. 19.—The general relationship of the Argus shells to the structure of the natural radiation zones. See references 4 and 5.



EXPLAINING ARGUS, Christofilos shows how magnetic field encompasses the earth (center). When nuclear bomb is detonated (symbol at lower right) some of its radiation is trapped and travels along lines of magnetic force to point at opposite end of line. Then it spreads around the earth in a thin shell of electrons.

TRIUMPH IN SPACE FOR A 'CRAZY GREEK'

Theory of Boston-born maverick scientist led to sensational Project Argus

Magnetic storms = strong ring current

Storm-time RC build-up involves

massive acceleration of ions,

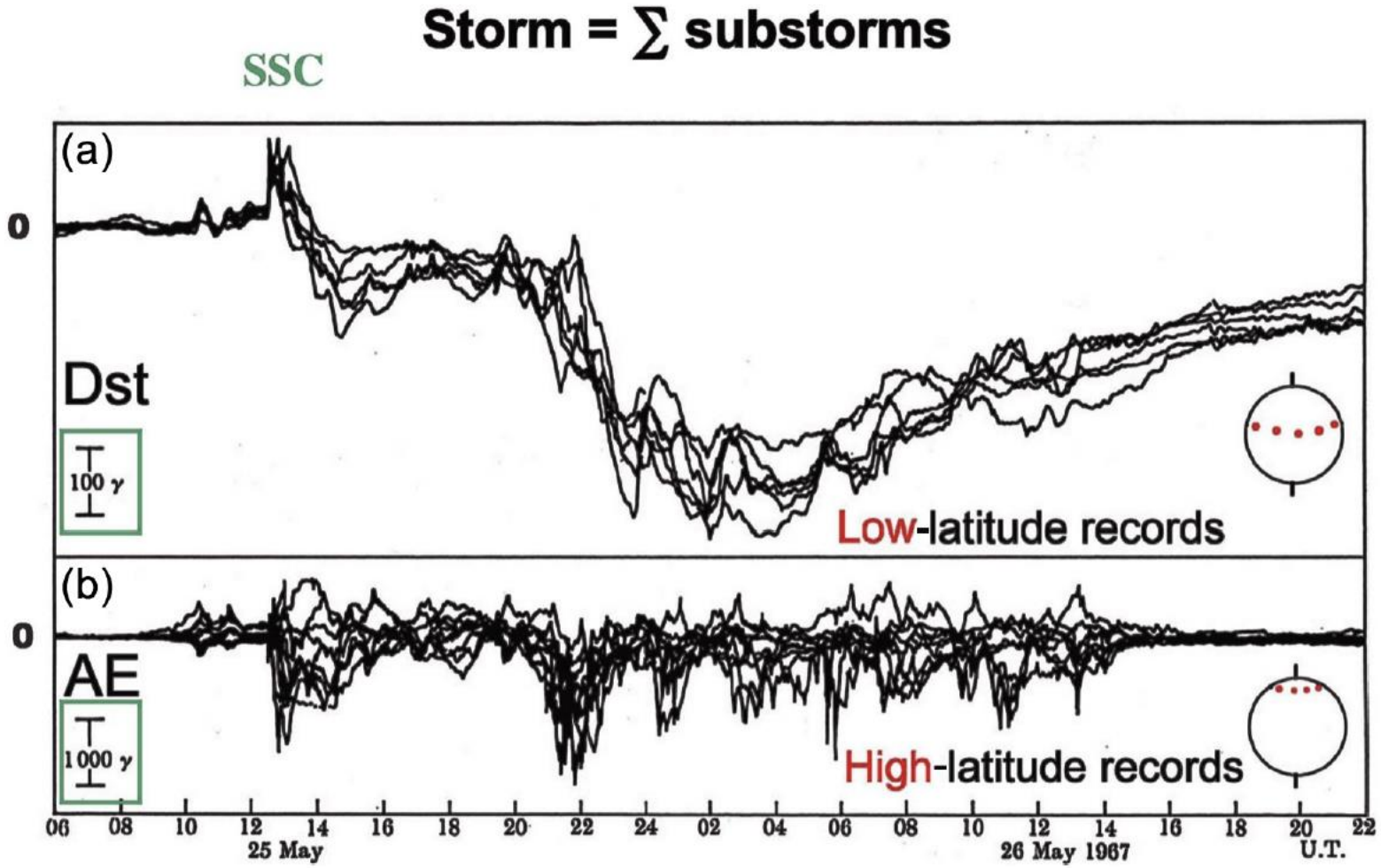
from a few keV to 100s keV.

Result of impulsive induced electric fields

or steady large-scale electric field?

(i.e. **substorms or convection?**)

The original Chapman-Akasofu storm-substorm concept



Rikubetsu 1994 (Kamide+, JGR1998)

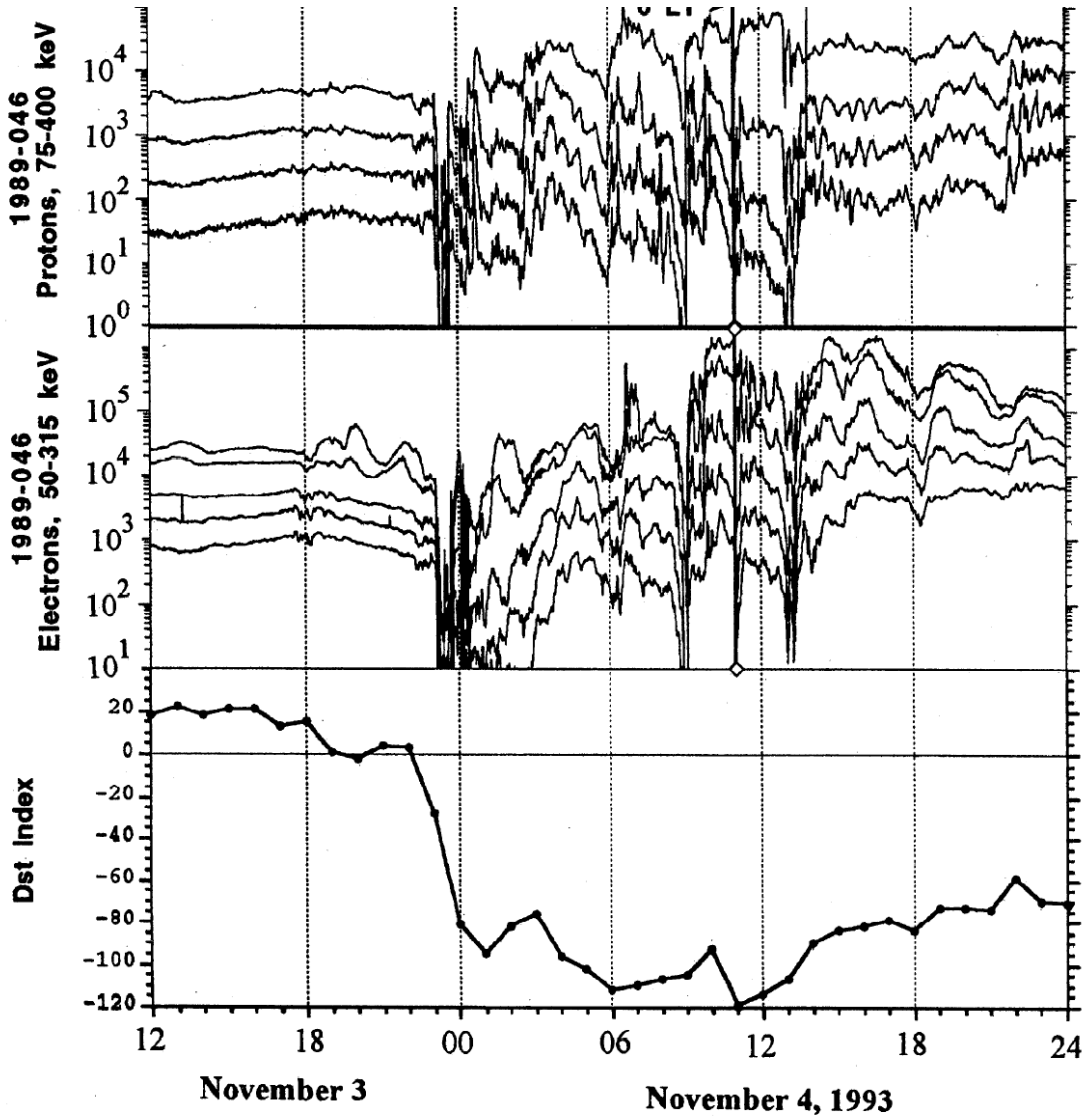


Figure 11. The response of geosynchronous energetic particles to the November 3-5, 1993, geomagnetic storm known as the "National Space Weather Event." The figure shows proton and electron fluxes from two geosynchronous satellites along with the *Dst* index for this period. Very strong injections of energetic particles are observed. However, a direct, quantitative relationship between geosynchronous injections and the development of *Dst* is difficult to establish.