Sources: Magnetohydrodynamic Waves

- Introduction to MHD waves (and beyond)

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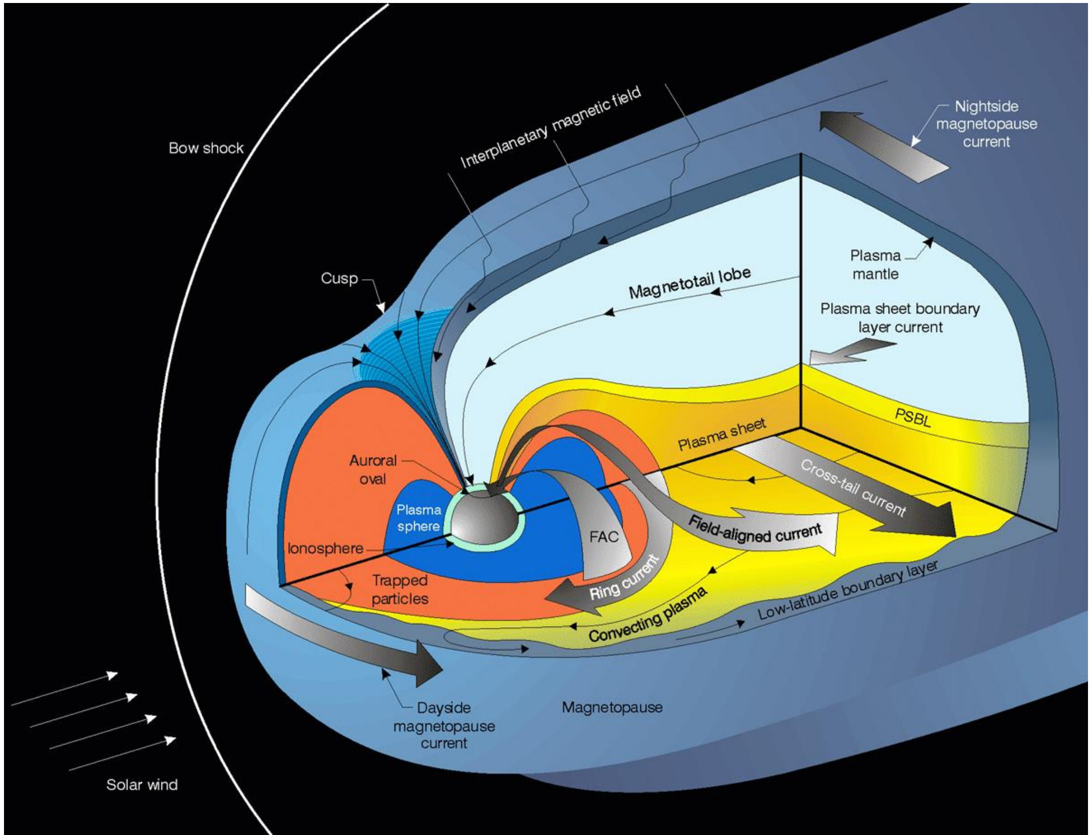
Introduction

- **Space: *in situ experiment***
- **Space is NOT empty and well structured.**
- **Space has all kinds of dynamics:**

Single-ptl + Kinetic + Fluid approach

L ~ 100,000km

dL ~ 100km



Introduction

(ground)	(space)
Sea: $\sim 10^{+22} / cm^3$	$\sim 10^{-2} - 10^{+3} / cm^3$
Air: $\sim 10^{+19} / cm^3$	
- **collisions dominant**	- **collisions negligible**
- **diffusive**	- **well-structured**
- **neutral ptls**	- **plasma (ions, electrons)**
- **mech. + gravit.**	- **mech. + electromag.**

cf) For CLIC beams,

$$n_e \square 10^{12\sim13} / (1nm, 40nm, 150ns * c) \sim 10^{21} / cm^3$$

Background: from single-ptl to fluid

- **Single-ptl** ***(e.g., f=ma)***

$$\vec{X}(t),\ \vec{V}(t) \qquad \vec{F} = m\frac{d\vec{V}}{dt} = q(\vec{E}+\vec{V}\times\vec{B})$$

- **A few or many ptls** ***(kinetic approach, f(x,v,t))***

$$N(\vec{x},\vec{v},\vec{t}) = \sum_j \delta(\vec{x}-\vec{X}_j(t))\ \delta(\vec{v}-\vec{V}_j(t)) \qquad f(\vec{x},\vec{v},t) \equiv < N(\vec{x},\vec{v},t) >$$

- **Multi-fluids** ***(multi-ions + electrons)***

$$n_j(\vec{x},t),\ \vec{V}_j(\vec{x},t),\ P_j(\vec{x},t),\ T_j(\vec{x},t) \qquad j = e, i$$

- **Single-fluid** ***(MHD)*** $n(\vec{x},t),\ \vec{V}(\vec{x},t),\ P(\vec{x},t),\ T(\vec{x},t)$

- **Ideal MHD**

Background: Multi-fluids *(multi-ions + electrons)*

- Multi-fluid equations

$$\frac{\partial n_j}{\partial t} + \nabla \cdot (n_j \mathbf{v_j}) = 0$$

$$m_j n_j \left[\frac{\partial \mathbf{v_j}}{\partial t} + (\mathbf{v_j} \cdot \nabla) \mathbf{v_j} \right] = n_j q_j (\mathbf{E} + \mathbf{v_j} \times \mathbf{B}) - \nabla p_j + \mathbf{R}_j \qquad j = i, e$$

$$p_j = C_j n_j^{\gamma_j}$$

- Ideal MHD equations

$$\frac{\partial n}{\partial t} + \nabla \cdot (n \mathbf{v}) = 0$$

$$mn \left[\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v} \right] = \mathbf{j} \times \mathbf{B} - \nabla p$$

$$p = C n^{\gamma}$$

$$\mathbf{E} + \mathbf{v} \times \mathbf{B} = 0$$

Approximations

- From *N(x,v,t)* to *f(x,v,t)* :

Neglect the single-particle nature

$$r >> \lambda_D = \sqrt{\frac{\epsilon_o k_B T}{n e^2}} \quad = \text{ the Debye length}$$

$$\Lambda = n{\lambda_D}^3 \;>>\; 1 \quad : \text{ the plasma parameter}$$

cf) For CLIC beams: $r \,\square\, \lambda_D$, but $\Lambda \,\square\, 1$

-From *f(x,v,t) {plasma kinetic eq.}*
to *f(x,v,t) {Vlasov eq.}*:

Neglect *collisions (resistivity)*
weak turbulence
quasi-linear theory
……

Approximations

- From *f(x,v,t)* to *MF(x,t)* :

Neglect the velocity distribution

ex) wave-particle interaction
microscopic instabilities
Landau damping
non-thermal equilibrium

- From *MF(x,t)* to *SF(x,t)* :

Neglect the electron inertia and the ion species

ex) rapid EM & ES variations

$$\omega < \omega_{ci} = \frac{eB}{m_i}$$ **Ion gyro-frequency**

$$r > r_{ci} = \frac{v_\perp}{\omega_{ci}}$$ **Ion gyro-radius**

Application – Waves in space

<MHD waves>

- ***very low freq:*** ***MHD waves*** $\omega << \Omega_i$

<multi-fluid waves>

- ***low freq:*** ***Ion waves*** $\omega \sim \Omega_i$
- ***intermed. freq:*** ***Ion-electron waves*** $\Omega_i < \omega < \Omega_e$
- ***high freq:*** ***Electron waves*** $\omega \sim \Omega_e$

<kinetic waves>

- ***e.g. higher harmonics, Bernstein waves, …***

<single-ptl resonances>

- ***e.g. bounce resonance, bounce-drift resonance, …***

Application – Waves in space

Maxwell eqs
+ Ohm's law →

$$\vec{\nabla} \times (\vec{\nabla} \times \vec{E}) = -\frac{1}{c^2}\frac{\partial^2 \vec{E}}{\partial t^2} - \mu_o \frac{\partial \vec{J}}{\partial t}$$
$$= \frac{\omega^2}{c^2}\left(\mathbf{I} + \frac{i\sigma}{\omega\epsilon_o}\right)\cdot \vec{E}$$
$$= k^2 \epsilon \cdot \vec{E}$$

For instance, $\vec{B} = B\,\hat{z},$

$$\epsilon = \begin{pmatrix} S & -iD & 0 \\ iD & S & 0 \\ 0 & 0 & P \end{pmatrix}$$

$$S = 1 - \sum_j \frac{\omega_{pj}^2}{\omega^2 - \omega_{cj}^2}$$
$$D = \sum_j \frac{|q_j|/q_j\ \omega_{cj}\omega_{pj}^2}{\omega(\omega^2 - \omega_{cj}^2)}$$
$$P = 1 - \sum_j \frac{\omega_{pj}^2}{\omega^2}$$

$$\omega_{pj} = \sqrt{\frac{n_j q_j^2}{m_j \epsilon_o}} \qquad \omega_{cj} = \frac{|q_j| B}{m_j}$$

Application – Waves

- CMA diagram

<multi-fluid waves>

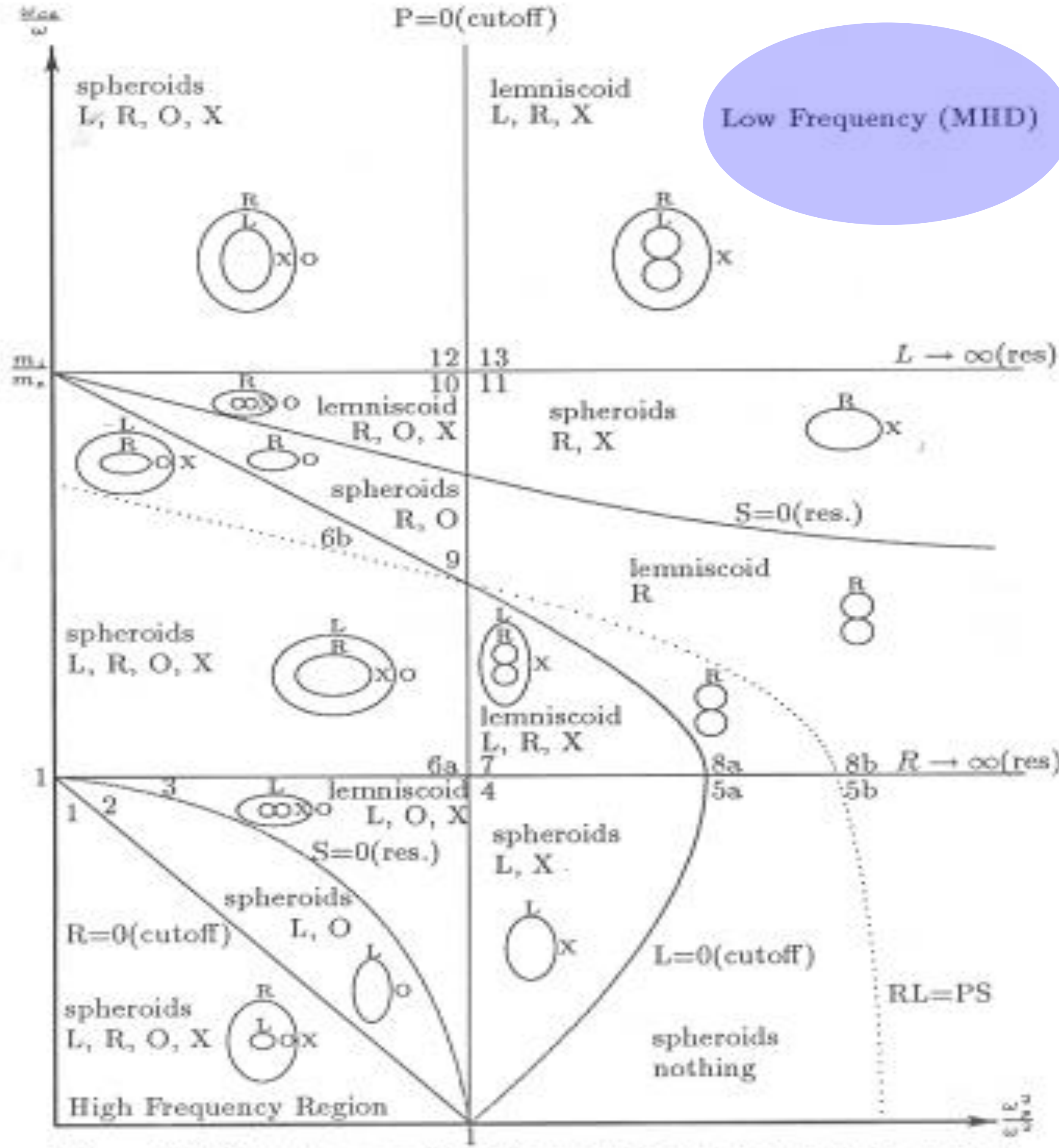


Figure 2.8: CMA diagram with all boundaries and wave normal surfaces.

Application – W

<electron waves>

<multi-ion waves>

[Fraser *et al.*, 1996]

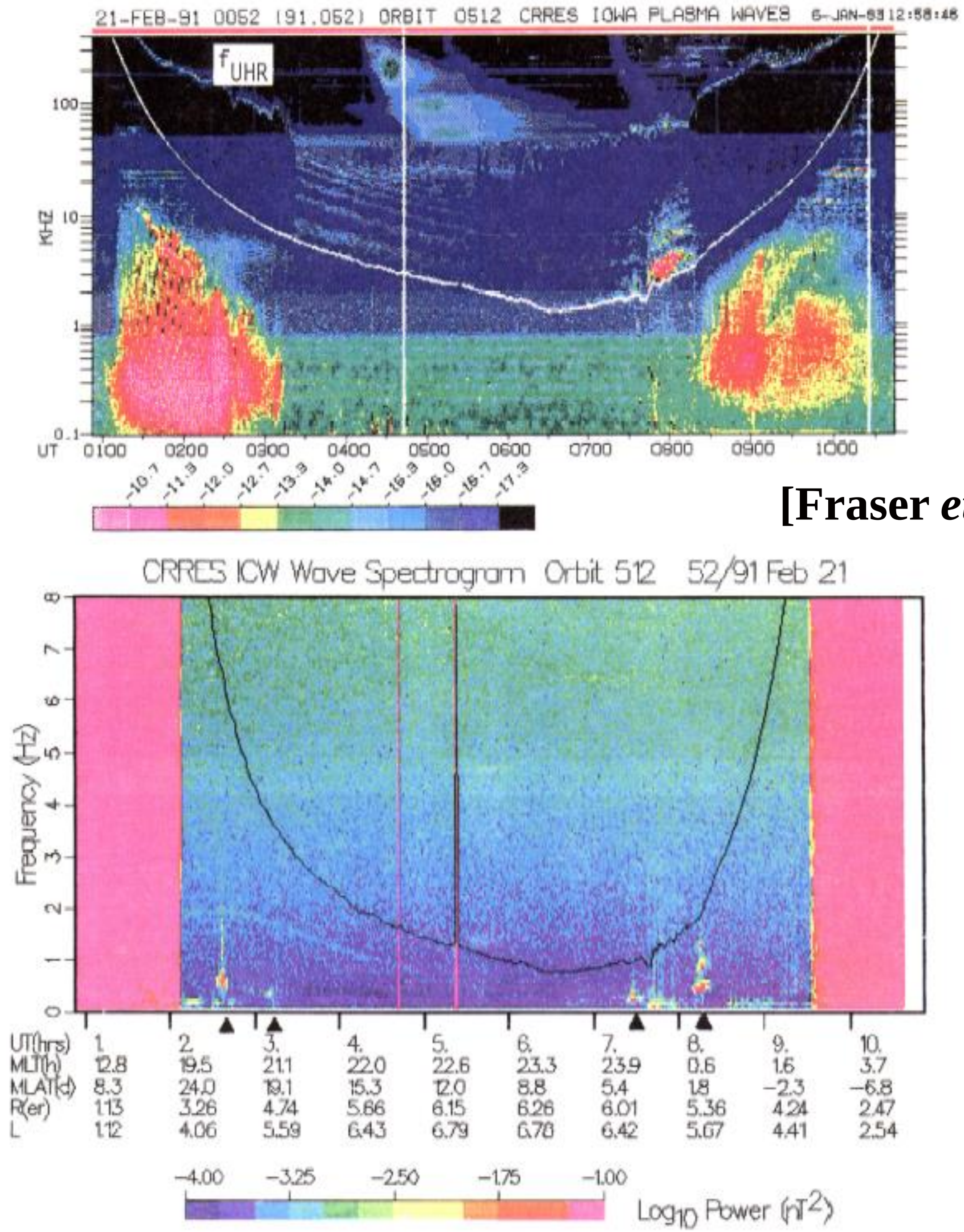
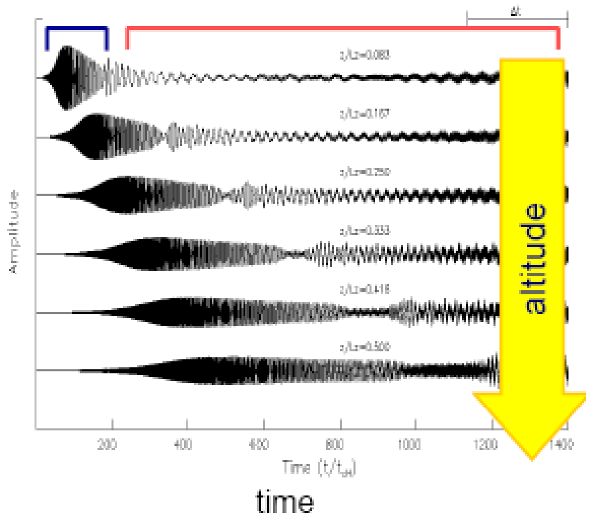


Plate 1. (Upper) CRRES EMIC wave dynamic spectrum for orbit 512 on February 21, 1991. The dark curve is the

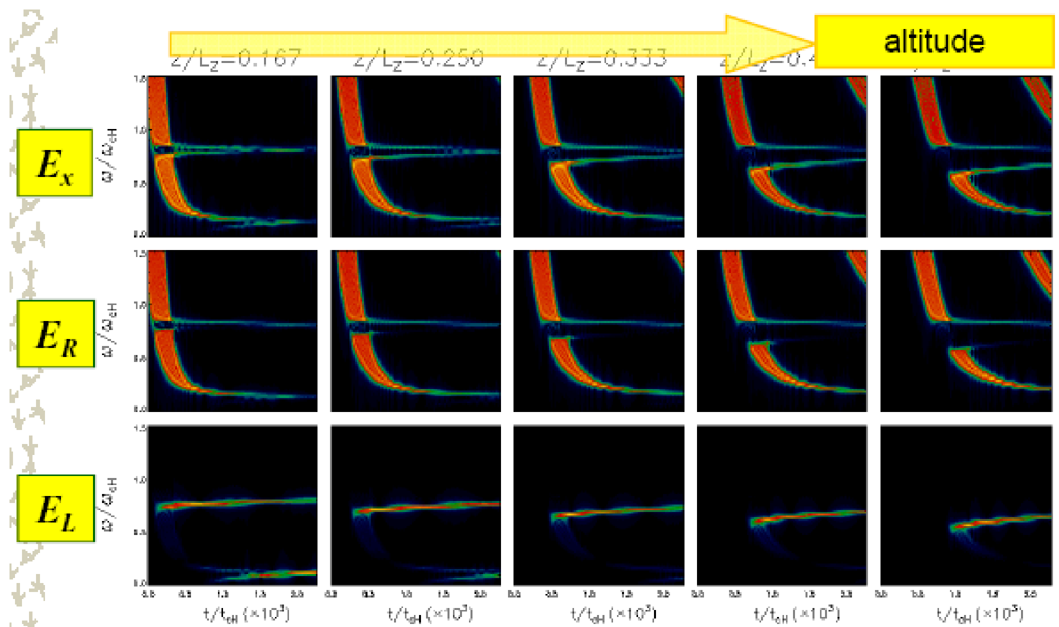
Application – Waves in space

- Two wave modes
  - First mode
    - Decreasing frequency with increasing time
  - Second mode
    - Appear after the reception of first wave modes
- Length of the wavetrains grows significantly with z.
- The time delay increases with z.



[Kim & Lee, 2005]

<ion-electron waves>



MHD waves

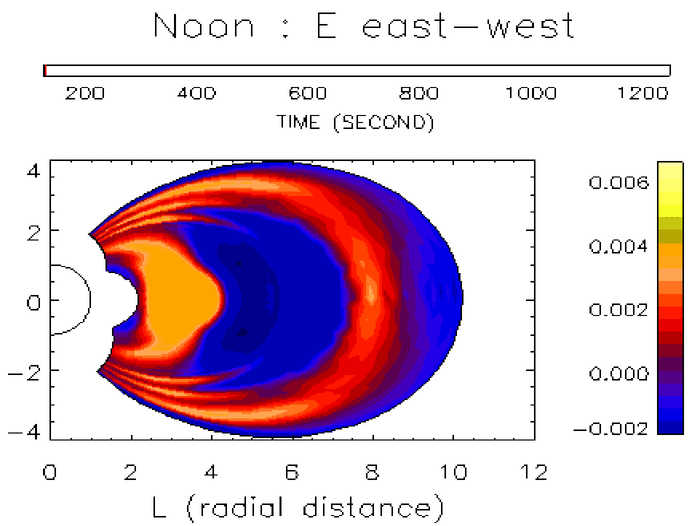
In uniform medium:

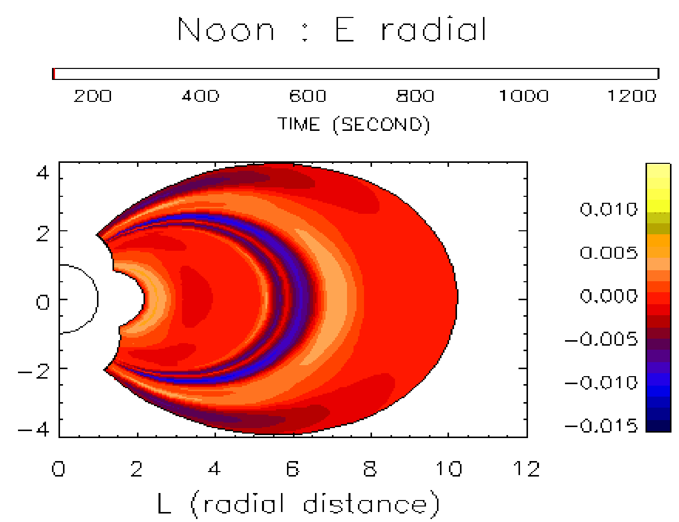
$$\omega = \frac{k V_A}{\sqrt{1 + \frac{i k^2}{\mu_o \omega \sigma}}}$$

- Compressional waves
- Magnetosonic waves
- Isotropic mode
- Three-dimensional

$$\omega = \frac{k_\parallel V_A}{\sqrt{1 + \frac{i k^2}{\mu_o \omega \sigma}}}$$

- Incompressional waves
- Alfven waves
- Anisotropic
- One-dimensional





* In a nonuniform plasma,

e.g., MHD waves: $\frac{\omega}{\omega_{cj}} \ll 1$ and $\rho(x), \quad V_A(x) = \frac{B}{\mu_o \rho(x)}$

$$S \approx \frac{c^2}{V_A^2}$$

$$D \approx 0$$

$$P \rightarrow \infty$$

Ex **: Alfven waves**
Ey **: Compressional waves**
Ez **= 0**

$$\vec{E} \propto e^{i(k_y y + k_z z - \omega t)} \qquad D = \frac{\omega^2}{V_A^2(x)} - k_z^2$$

$$\left(\frac{d}{dx} \frac{D}{D - k_y^2} \frac{dE_y}{dx} \right) + D\, E_y = 0$$

- MHD waves: *Asymptotic solutions*

At resonances,

$$E_x \propto \frac{1}{x - x_0}$$

$$E_y \propto ln|x - x_0|$$

$$\frac{\omega^2}{V_A^2} - k_z^2 = \alpha \, (x - x_0) = C \, (\omega - \omega_0)$$

→ $E_y(x, t \to \infty) \propto \frac{1}{2\pi}\int_{-\infty}^{\infty} ln|\omega - \omega_0| e^{-i\omega t} d\omega = -\frac{1}{2t} e^{-i\omega_0 t}$

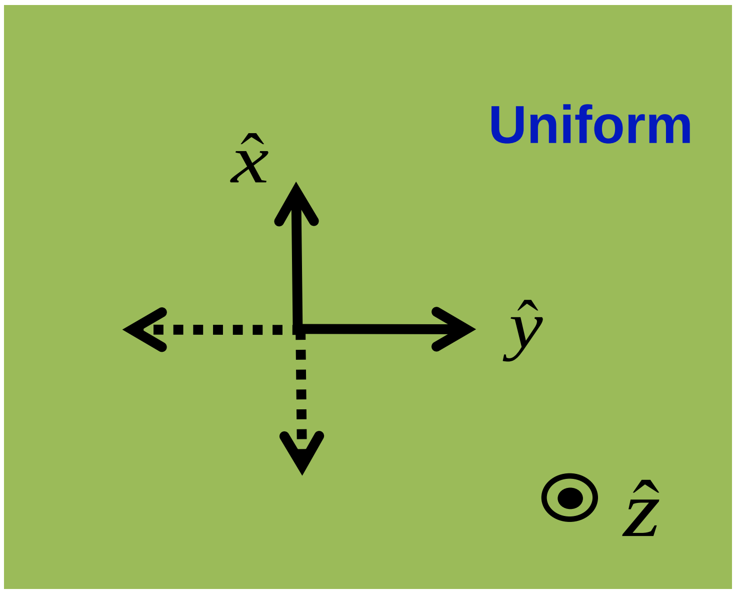
→ ***Ey* is being damped to *Ex (even if no dissipations)***

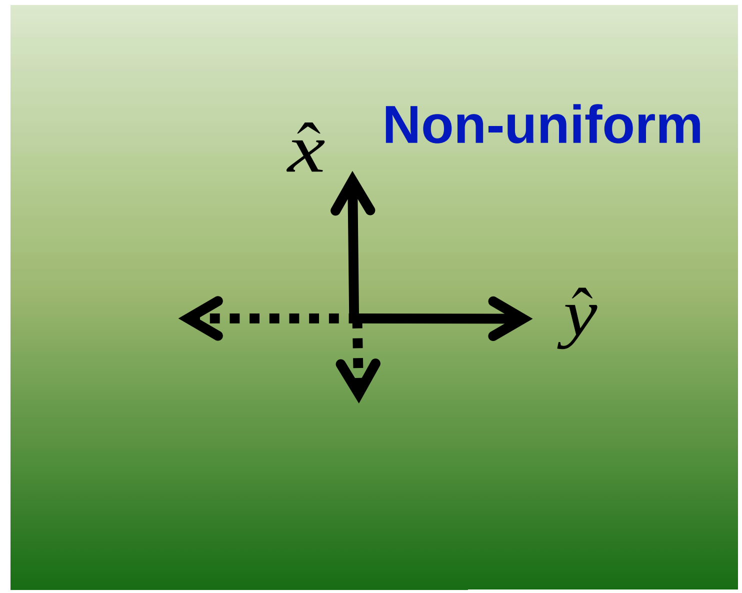
→ **Compressional waves damp, shear Alfven waves grow.**

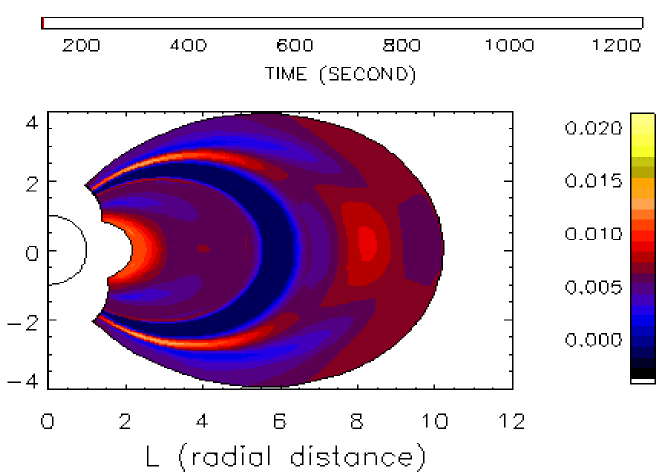
→ **Resonant absorption of Alfven waves = Field line resonances**

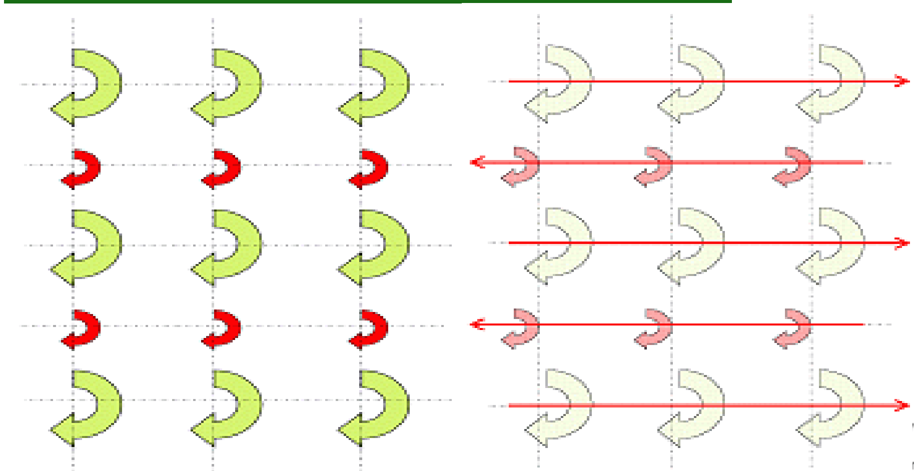
→ ***Mode conversion***

- **Two degrees of freedom become differential in nonuniform plasmas.**
- **In terms of wave (collective) motion, azimuthal or shear motion is stable.**

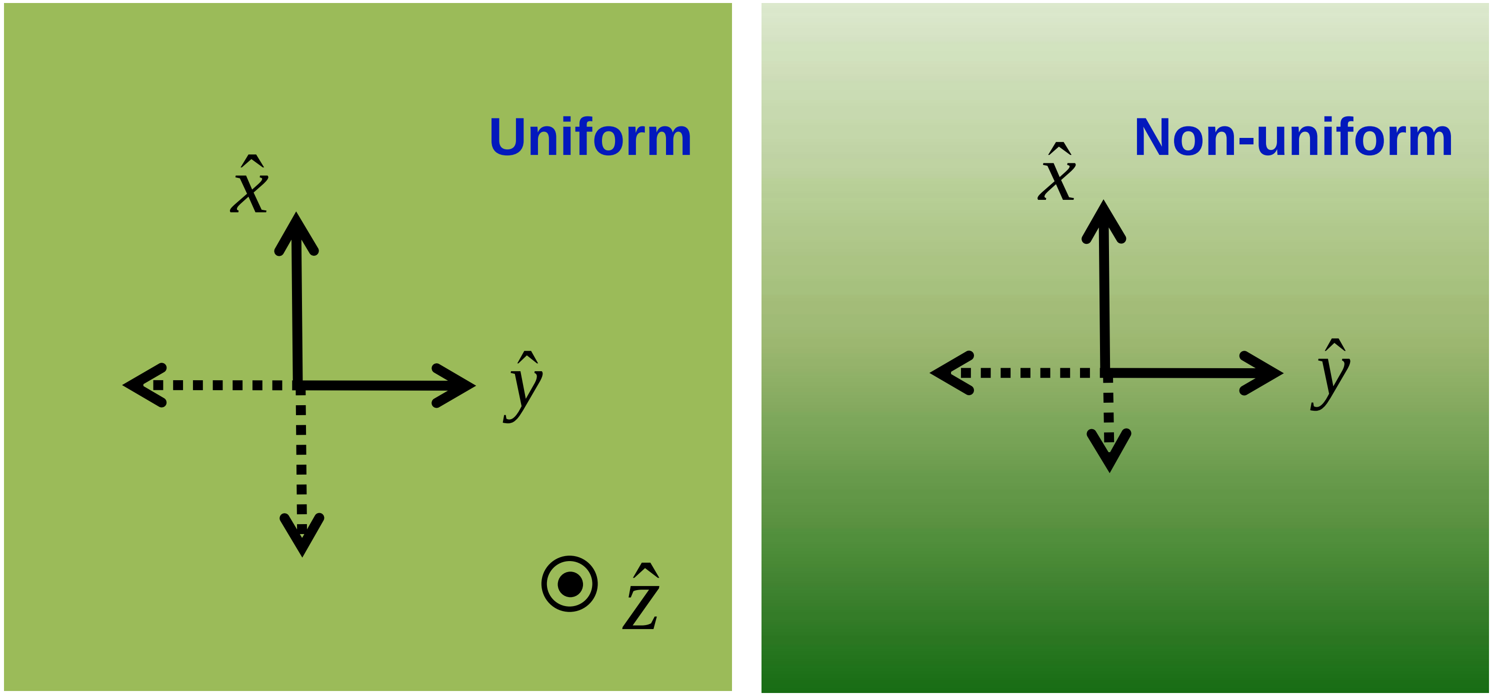








$$\vec{E} + \vec{v} \times \vec{B}_o = 0$$ **is valid for collective, but relatively low frequency wave motion.**



- When inhomo. lies perpendicular to B-field, the azimuthal (shear) motion Vy or radial Ex or azimuthal By are expected to be stable(and dominant?).

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* Torodial & Poloidal modes

$$\vec{\nabla}\times\vec{b} = \frac{1}{V_A^{\,2}(\vec{x},t)}\frac{\partial \vec{E}}{\partial t}$$

$$\vec{\nabla}\times\vec{E} = -\frac{\partial \vec{b}}{\partial t}$$

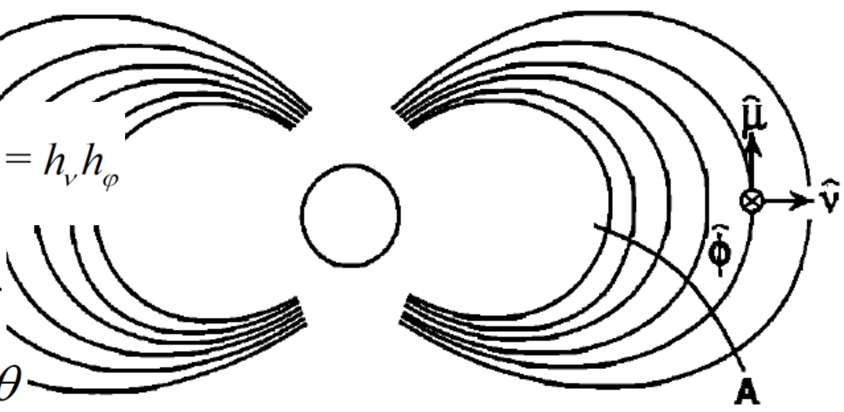
$$\varepsilon_\nu = h_\nu E_\nu$$

$$\varepsilon_\varphi = h_\varphi E_\varphi$$

$$h_\mu = \frac{B_E R_E^3}{B_o(\vec{r})} = h_\nu h_\varphi$$

$$h_\nu = \frac{B_E R_E^3}{h_\varphi B_o}$$

$$h_\varphi = r\cos\theta$$



$$\frac{\partial \beta_\mu}{\partial t} = -\left\{\frac{\partial \varepsilon_\varphi}{\partial \nu} - \frac{\partial \varepsilon_\nu}{\partial \varphi}\right\} = -\left\{\frac{\partial \varepsilon_\varphi}{\partial \nu} + im\varepsilon_\nu\right\}$$

In the dipole coordinate $(\mu,\ \nu,\ \varphi)$

$$\left\{\frac{1}{V_A^2}\frac{\partial^2}{\partial t^2} - \frac{1}{h_\varphi^2}\frac{\partial}{\partial \mu}\left(\frac{1}{h_\nu^2}\frac{\partial}{\partial \mu}\right)\right\}\varepsilon_\nu = -\frac{1}{h_\varphi^2}\frac{\partial}{\partial \varphi}\left\{\frac{\partial \varepsilon_\varphi}{\partial \nu} - \frac{\partial \varepsilon_\nu}{\partial \varphi}\right\} = \frac{1}{h_\varphi^2} im \left\{\frac{\partial \varepsilon_\varphi}{\partial \nu} + im\varepsilon_\nu\right\}$$

$$\left\{\frac{1}{V_A^2}\frac{\partial^2}{\partial t^2} - \frac{1}{h_\nu^2}\frac{\partial}{\partial \mu}\left(\frac{1}{h_\varphi^2}\frac{\partial}{\partial \mu}\right)\right\}\varepsilon_\varphi = \frac{1}{h_\nu^2}\frac{\partial}{\partial \nu}\left\{\frac{\partial \varepsilon_\varphi}{\partial \nu} - \frac{\partial \varepsilon_\nu}{\partial \varphi}\right\} = \frac{1}{h_\nu^2}\frac{\partial}{\partial \nu}\left\{\frac{\partial \varepsilon_\varphi}{\partial \nu} + im\varepsilon_\nu\right\}$$

$$\left\{\frac{1}{V_A^2}\frac{\partial^2}{\partial t^2} - \frac{1}{h_\varphi^2}\frac{\partial}{\partial \mu}\left(\frac{1}{h_\nu^2}\frac{\partial}{\partial \mu}\right)\right\}\varepsilon_\nu = 0$$

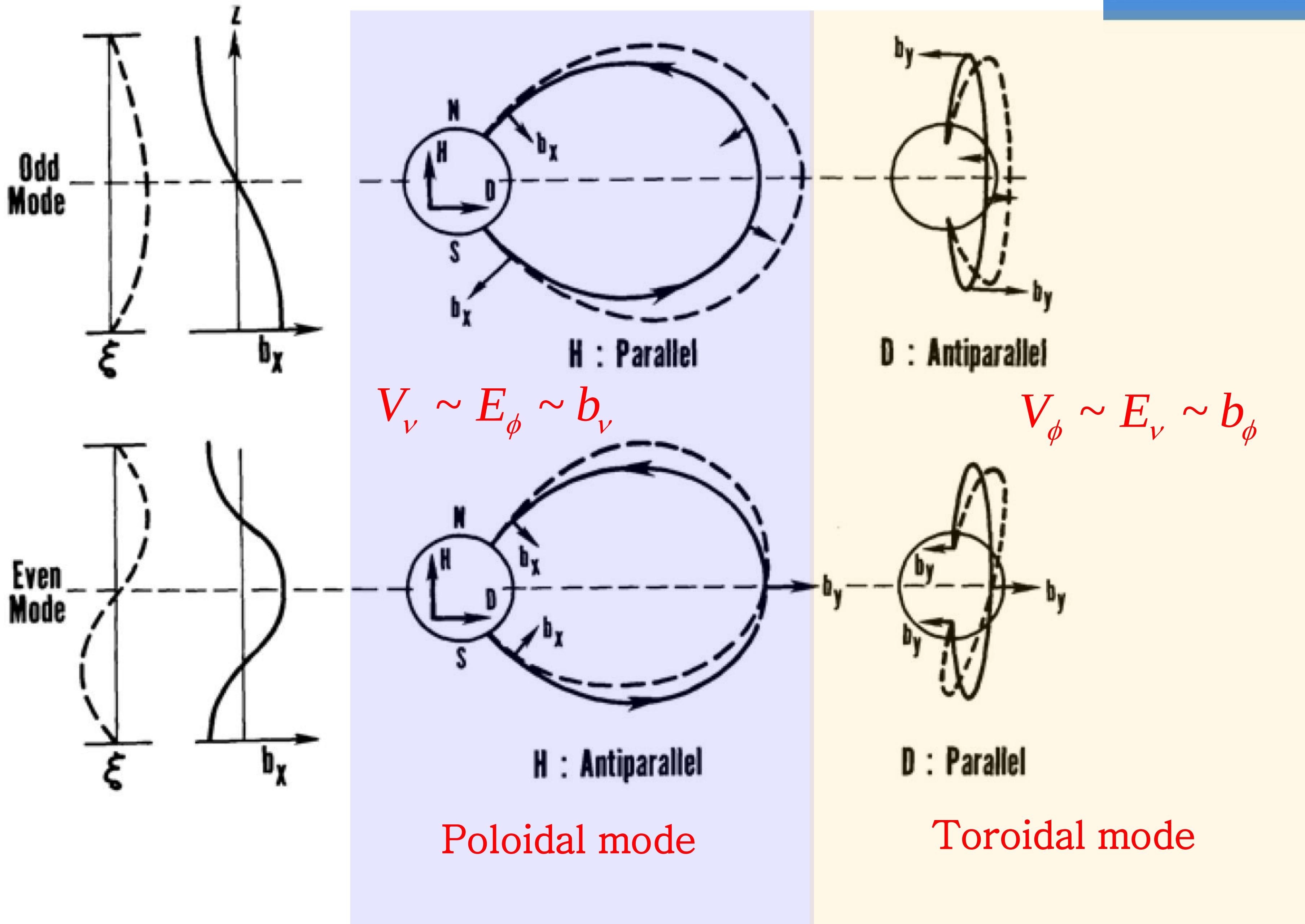
Toroidal: $m = 0$

$$\left\{\frac{1}{V_A^2}\frac{\partial^2}{\partial t^2} - \frac{1}{h_\nu^2}\frac{\partial}{\partial \mu}\left(\frac{1}{h_\varphi^2}\frac{\partial}{\partial \mu}\right)\right\}\varepsilon_\varphi = 0$$

Poloidal: $m \to \infty$

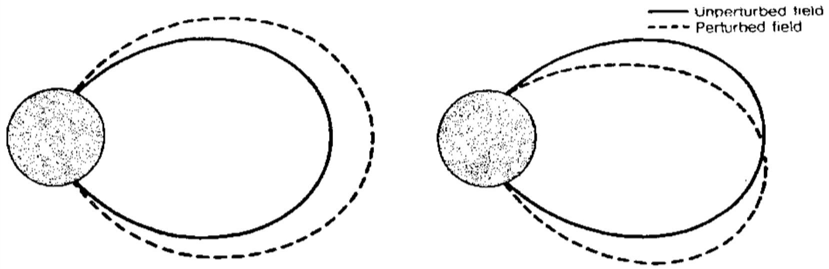
* Torodial & Poloidal modes

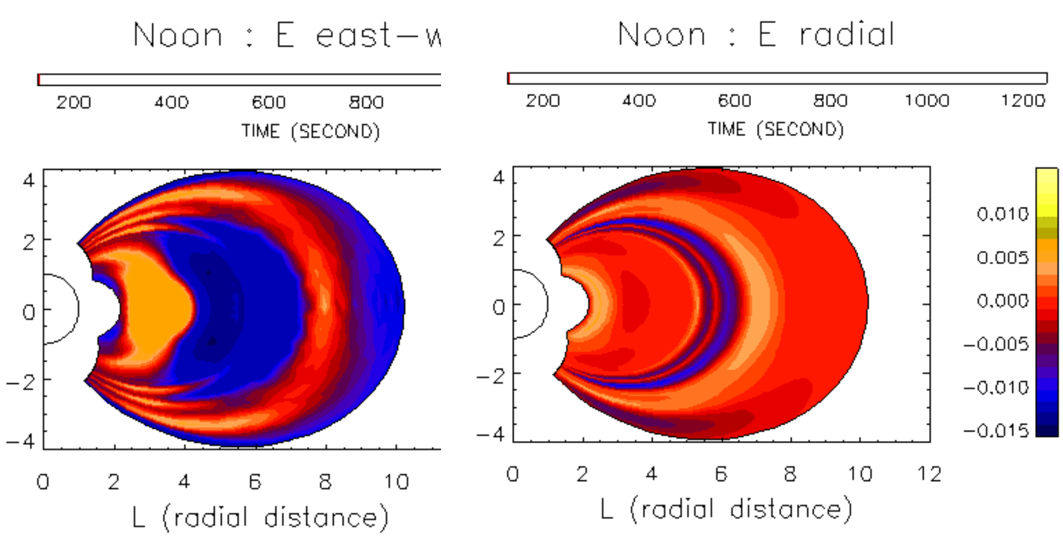
[McPherron, 2005]

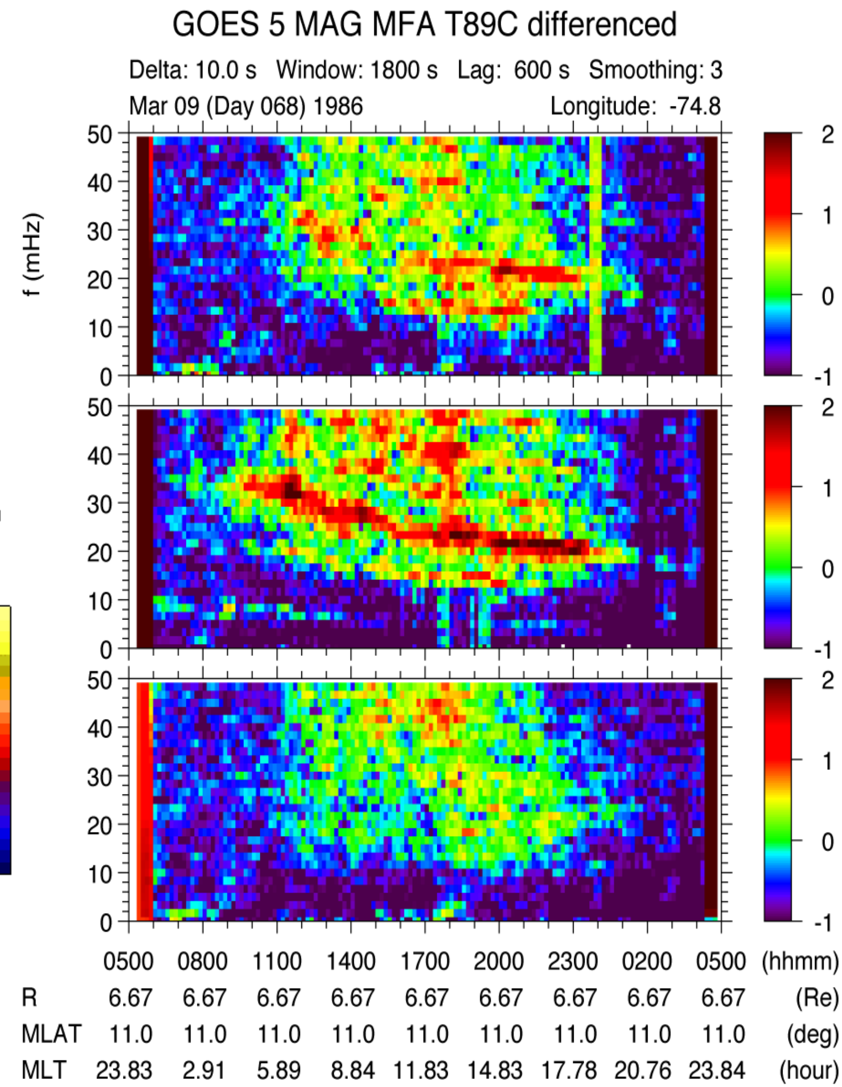


Application – Waves in space

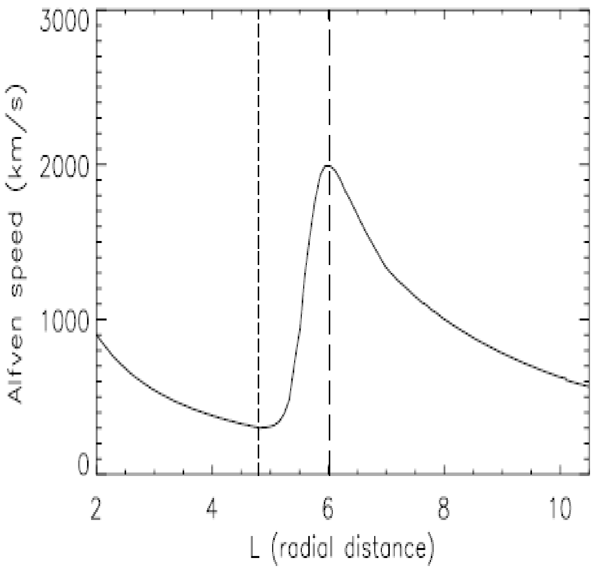
<MHD waves>







- 3-D dipole MHD waves

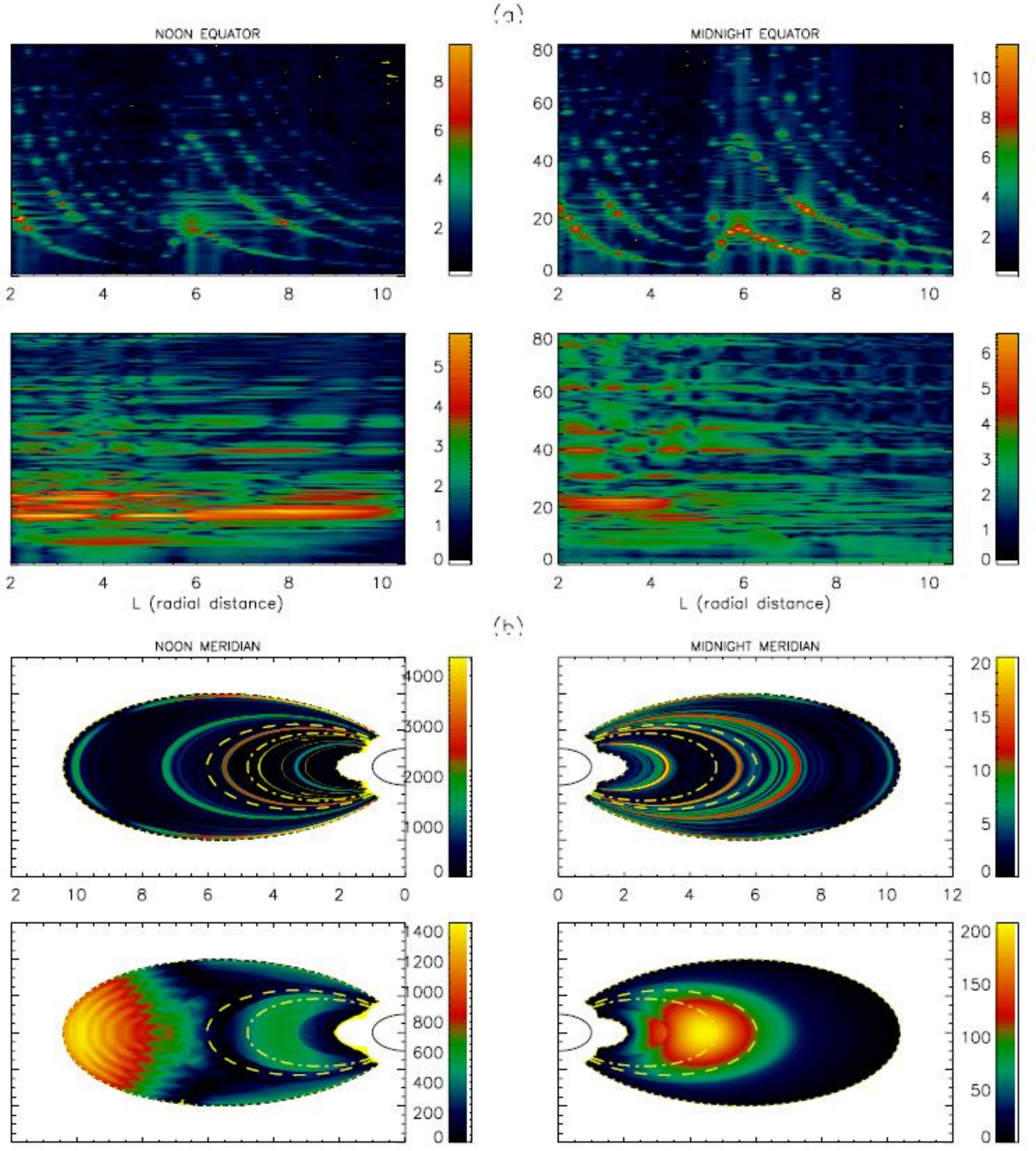


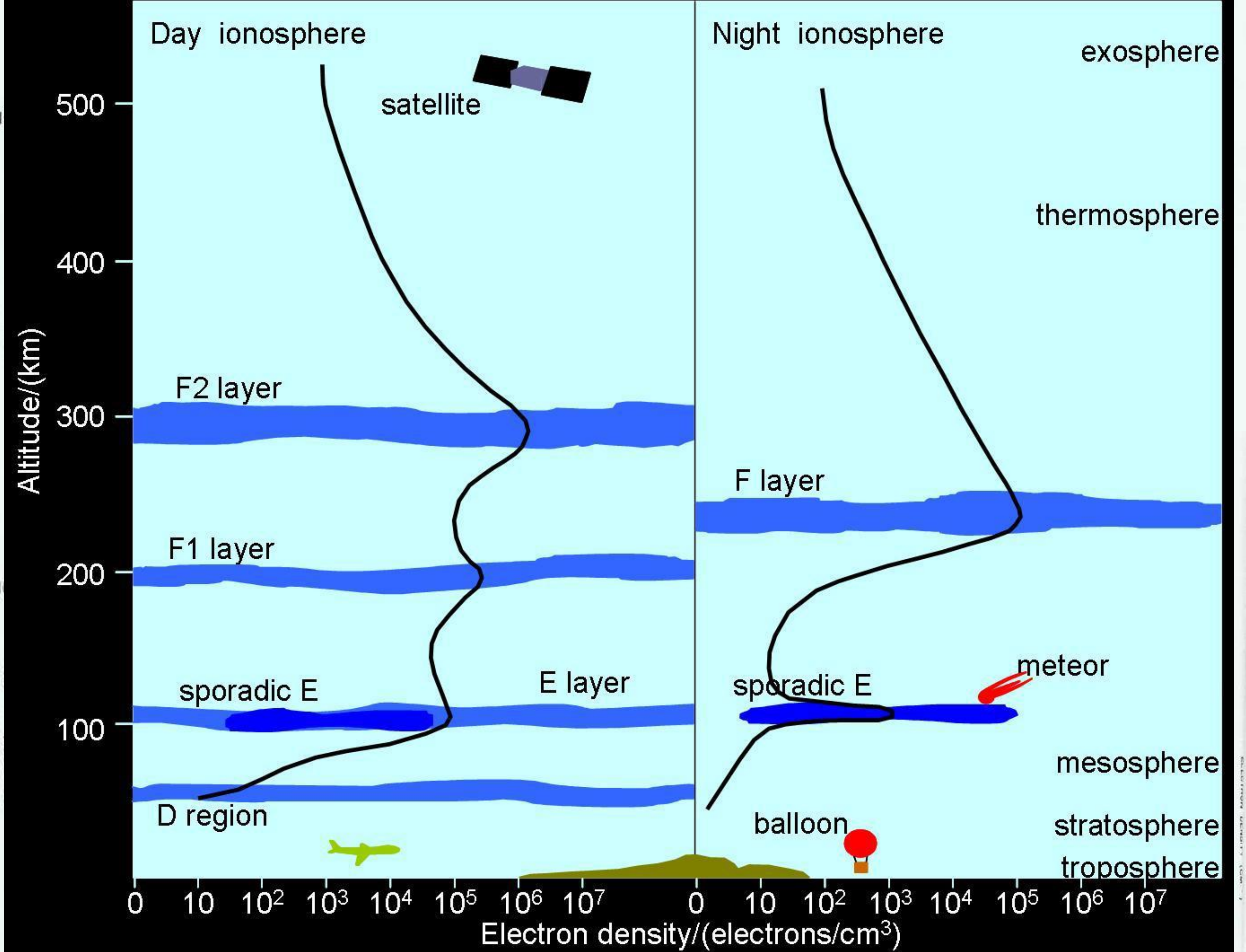
[e.g., Lee *et al.*, 2004]

cf) For CLIC,

λ_{lat} □ 47^o

L □ 2.1Re





Day ionosphere
Night ionosphere
exosphere
satellite
500
thermosphere
400
Altitude/(km)
F2 layer
300
F layer
F1 layer
200
meteor
sporadic E
E layer
sporadic E
100
mesosphere
D region
balloon
stratosphere
troposphere
0 10 10² 10³ 10⁴ 10⁵ 10⁶ 10⁷ 0 10 10² 10³ 10⁴ 10⁵ 10⁶ 10⁷
Electron density/(electrons/cm³)

Collisions with ***neutral*** ptls

*** Assume:** $\vec{v_n} = 0$

- Eqs of motion:

$$m_i \frac{\partial \vec{v_i}}{\partial t} = e\left(\vec{E} + \vec{v_i} \times \vec{B}\right) - m_i \nu_{in} \vec{v_i}$$

$$m_e \frac{\partial \vec{v_e}}{\partial t} = -e\left(\vec{E} + \vec{v_e} \times \vec{B}\right) - m_e \nu_{en} \vec{v_e}$$

$$\Rightarrow \quad \vec{J} = \overleftrightarrow{\sigma} \cdot \vec{E} = \begin{pmatrix} \sigma_P & -\sigma_H & 0 \\ \sigma_H & \sigma_P & 0 \\ 0 & 0 & \sigma_\parallel \end{pmatrix} \cdot \begin{pmatrix} E_x \\ E_y \\ E_z \end{pmatrix}$$

$$\Rightarrow \quad \vec{J} = \sigma_\parallel \vec{E_\parallel} + \sigma_P \vec{E_\perp} - \sigma_H \frac{\vec{E} \times \vec{B}}{B}$$

Collisions with ***neutral*** ptls

where

$$\sigma_P = \epsilon_o \sum_j \frac{\omega_{pj}{}^2 (\nu_{jn} - i\omega)}{(\nu_{jn} - i\omega)^2 + \omega_{cj}{}^2}$$

$$\sigma_H = -\epsilon_o \sum_j \frac{\epsilon_j \, \omega_{pj}{}^2 \, \omega_{cj}}{(\nu_{jn} - i\omega)^2 + \omega_{cj}{}^2}$$

$$\sigma_\parallel = \epsilon_o \sum_j \frac{\omega_{pj}{}^2}{\nu_{jn} - i\omega}$$

If $\omega \ll \nu_{jn}$

$$\sigma_P \cong \epsilon_o \sum_j \frac{\omega_{pj}{}^2 \, \nu_{jn}}{\nu_{jn}{}^2 + \omega_{cj}{}^2} = \left(\frac{\nu_{en}}{\nu_{en}{}^2 + \omega_{ce}{}^2} + \frac{m_e}{m_i} \frac{\nu_{in}}{\nu_{in}{}^2 + \omega_{ci}{}^2} \right) \frac{n_e e^2}{m_e}$$

$$\sigma_H \cong -\epsilon_o \sum_j \frac{\epsilon_j \, \omega_{pj}{}^2 \, \omega_{cj}}{\nu_{jn}{}^2 + \omega_{cj}{}^2} = \left(\frac{\omega_{ce}}{\nu_{en}{}^2 + \omega_{ce}{}^2} - \frac{m_e}{m_i} \frac{\omega_{ci}}{\nu_{in}{}^2 + \omega_{ci}{}^2} \right) \frac{n_e e^2}{m_e}$$

$$\sigma_\parallel \cong \epsilon_o \sum_j \frac{\omega_{pj}{}^2}{\nu_{jn}} = \left(\frac{1}{\nu_{en}} + \frac{m_e}{m_i} \frac{1}{\nu_{in}} \right) \frac{n_e e^2}{m_e}$$

Collisions with ***neutral*** ptls

since $$\frac{\sigma_P(j)}{\sigma_H(j)} \approx \frac{\nu_{jn}}{\omega_{cj}}$$

$$\omega_{cj} \ll \nu_{jn} \qquad \sigma_P(j) \gg \sigma_H(j)$$

$$\omega_{cj} \gg \nu_{jn} \qquad \sigma_P(j) \ll \sigma_H(j)$$

$$\frac{\omega_{ce}}{\omega_{ci}} = \frac{m_i}{m_e} = 1836$$

$$\frac{\nu_{en}}{\nu_{in}} = \sqrt{\frac{m_i}{m_n}} = \sqrt{1836} \cong 43$$

There are 3 choices:

$$\omega_{ci} \ll \omega_{ce} \lesssim \nu_{in} \ll \nu_{en}$$: **both P currents dominant**

→ $$\omega_{ci} \ll \nu_{in} \ll \nu_{en} \ll \omega_{ce}$$: **P(i) and H(e)**

$$\nu_{in} \ll \nu_{en} \ll \omega_{ci} \ll \omega_{ce}$$: **both H currents dominant**

* Ionosphere: *Composition*

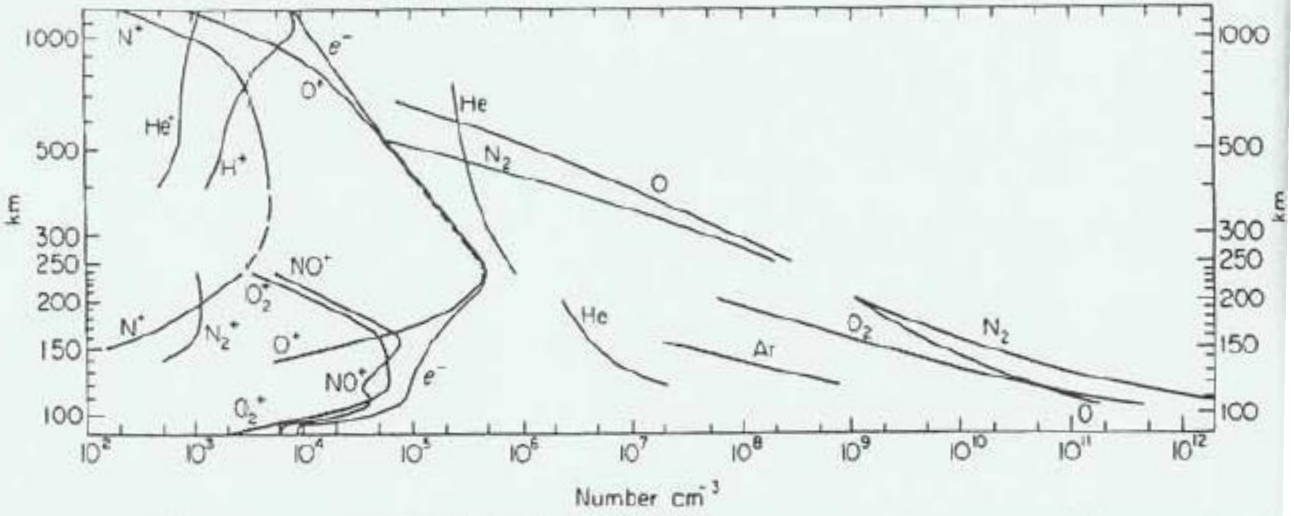
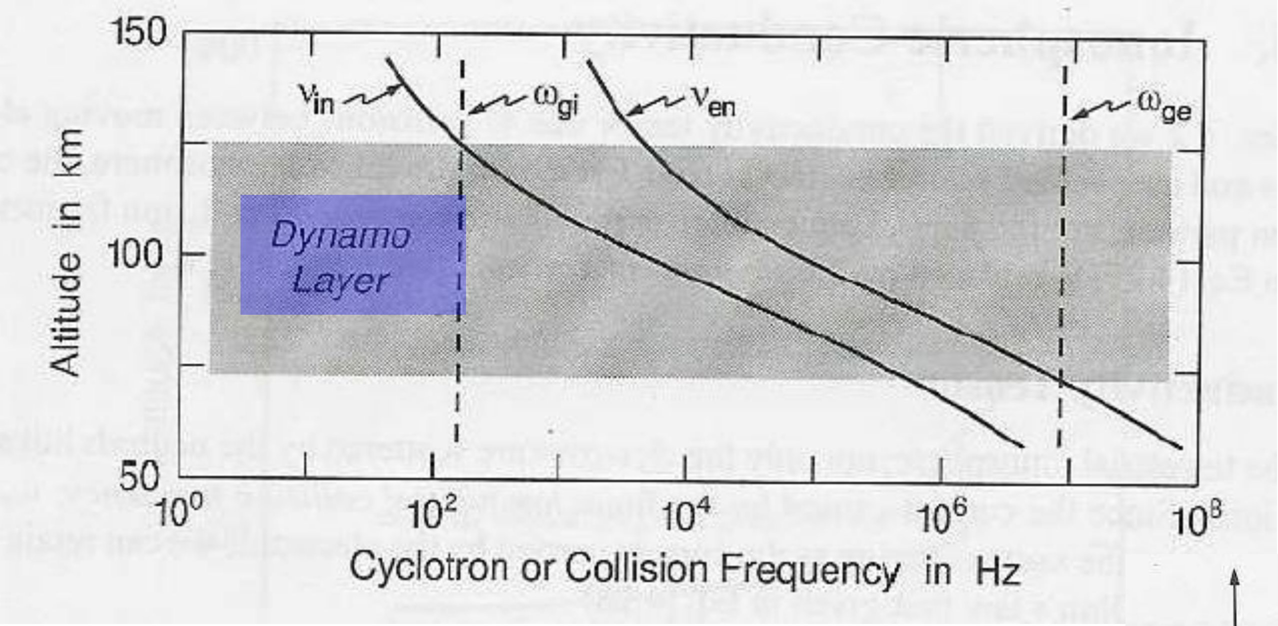


Fig. 1.2. International Quiet Solar Year (IQSY) daytime atmospheric composition, based on mass spectrometer measurements above White Sands, New Mexico (32°N, 106°W). The helium distribution is from a nighttime measurement. Distributions above 250 km are from the Elektron II satellite results of Istomin (1966) and Explorer XVII results of Reber and Nicolet (1965). [C. Y. Johnson, U.S. Naval Research Laboratory, Washington, D.C. Reprinted from Johnson (1969) by permission of the MIT Press, Cambridge, Massachusetts. Copyright 1969 by MIT.]

Collisions with ***neutral*** ptls



$$\omega_{ci} \ll \nu_{in} \ll \nu_{en} \ll \omega_{ce}$$

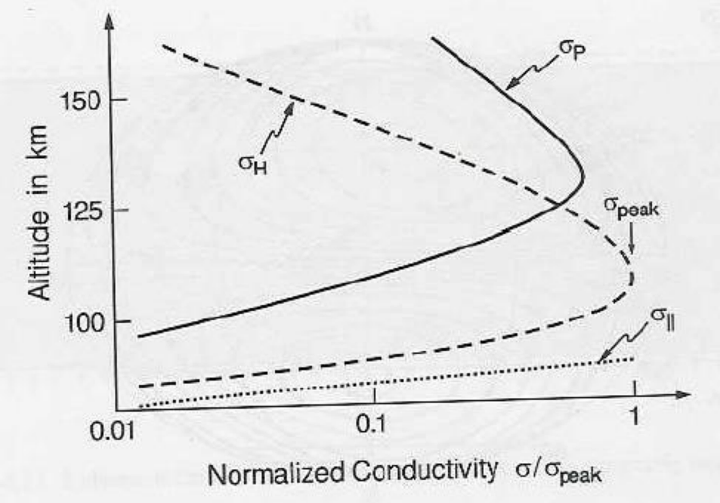
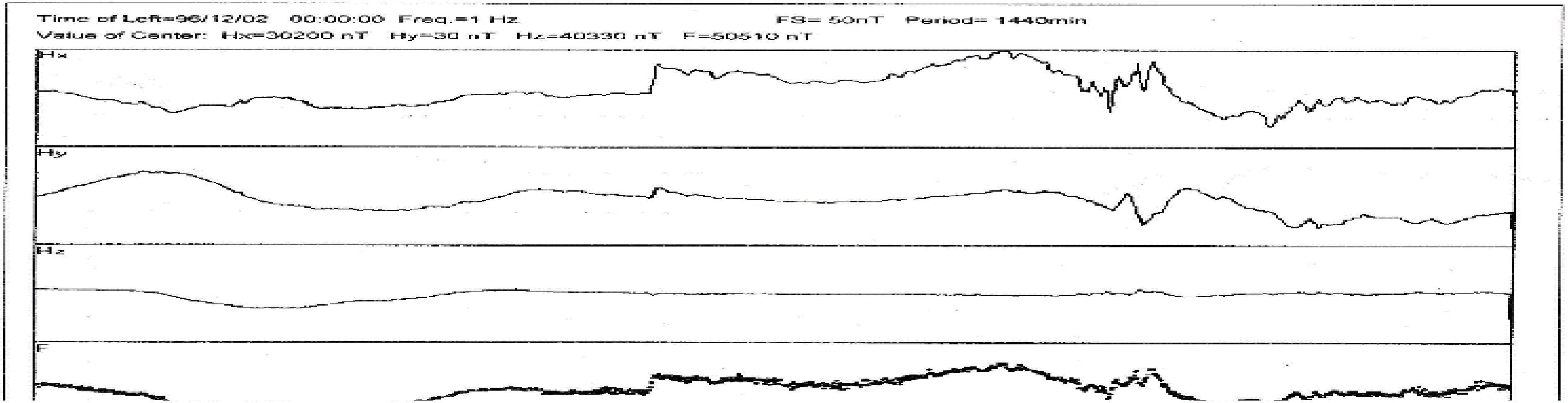


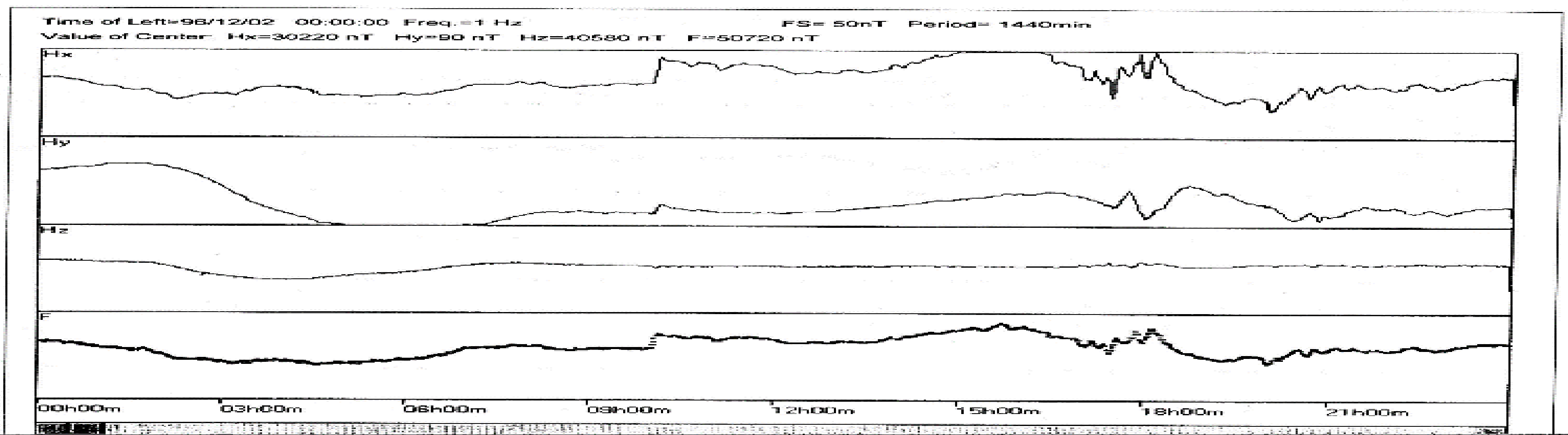
Fig. 4.11. Height profiles of normalized conductivities.

(*After* Baumjohann & Treumann, 1996)

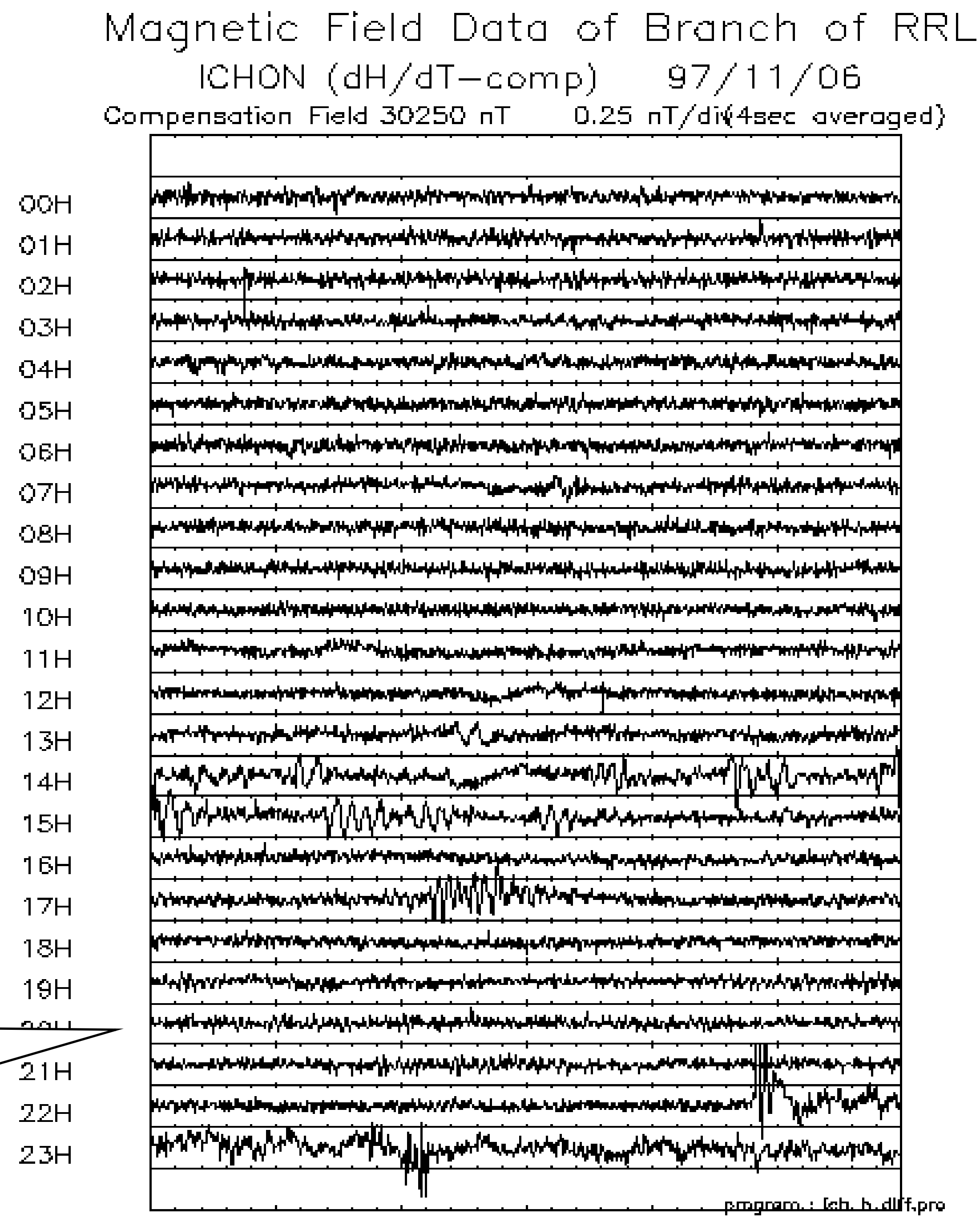
* CME observations at the two near-by stations (< 60km)

- **1996.12.02 09:30 - 10:30(UT) at Icheon, Yongin station**





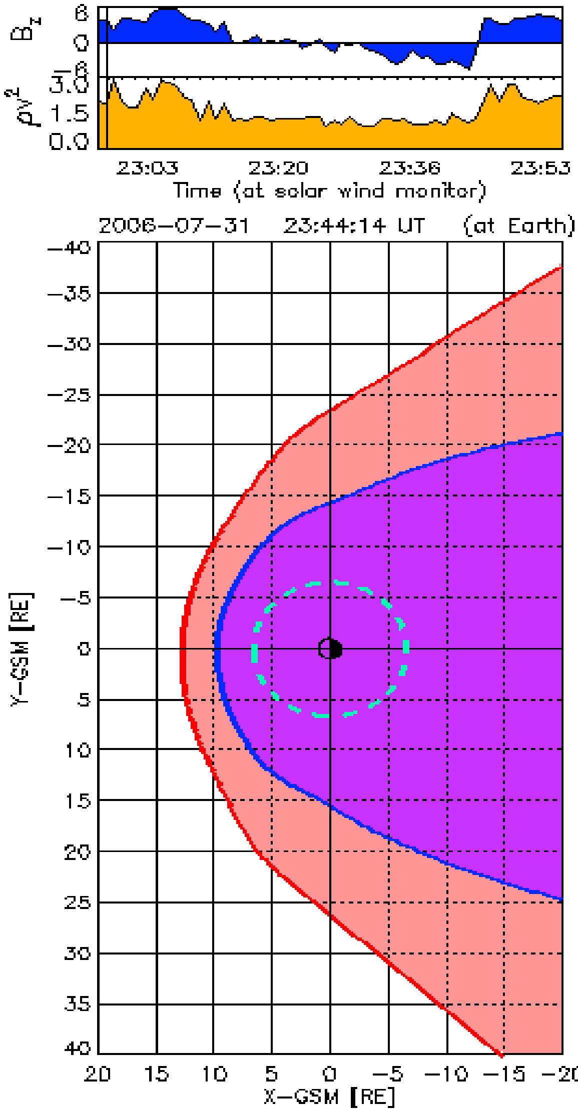
- **daily variations**



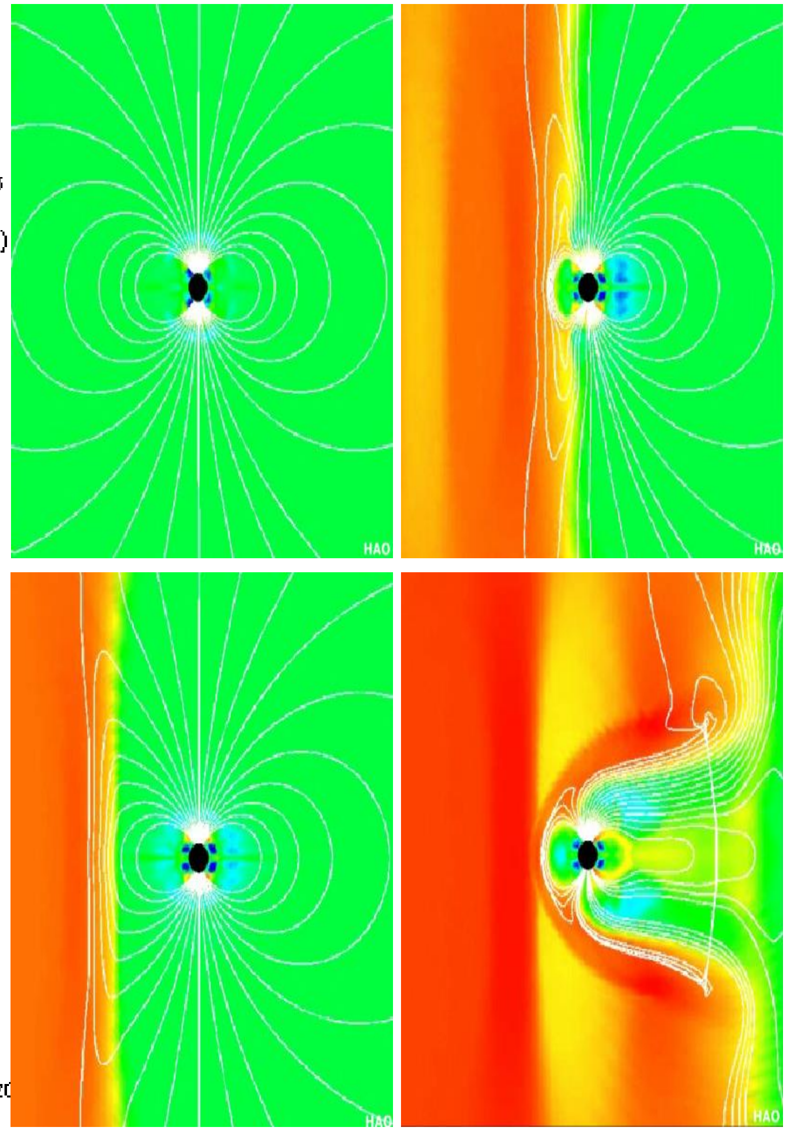
97/11/06
이천 전파연구소
관측자료

Application - Magnetospheric dynamics

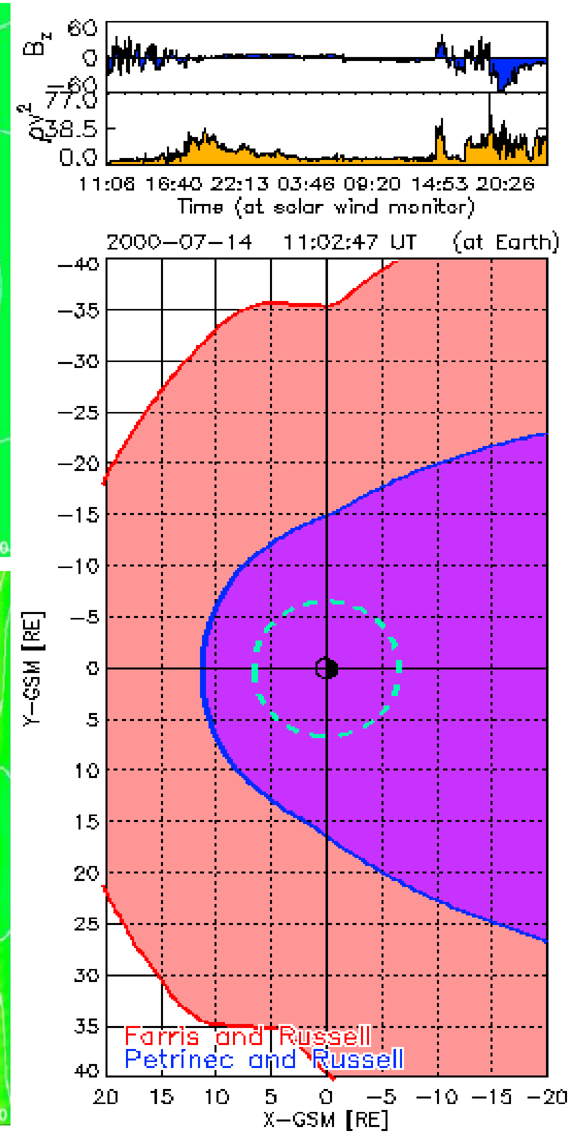
❑ 2006년 7월 31일(평온)



[Petrinec, 1994]

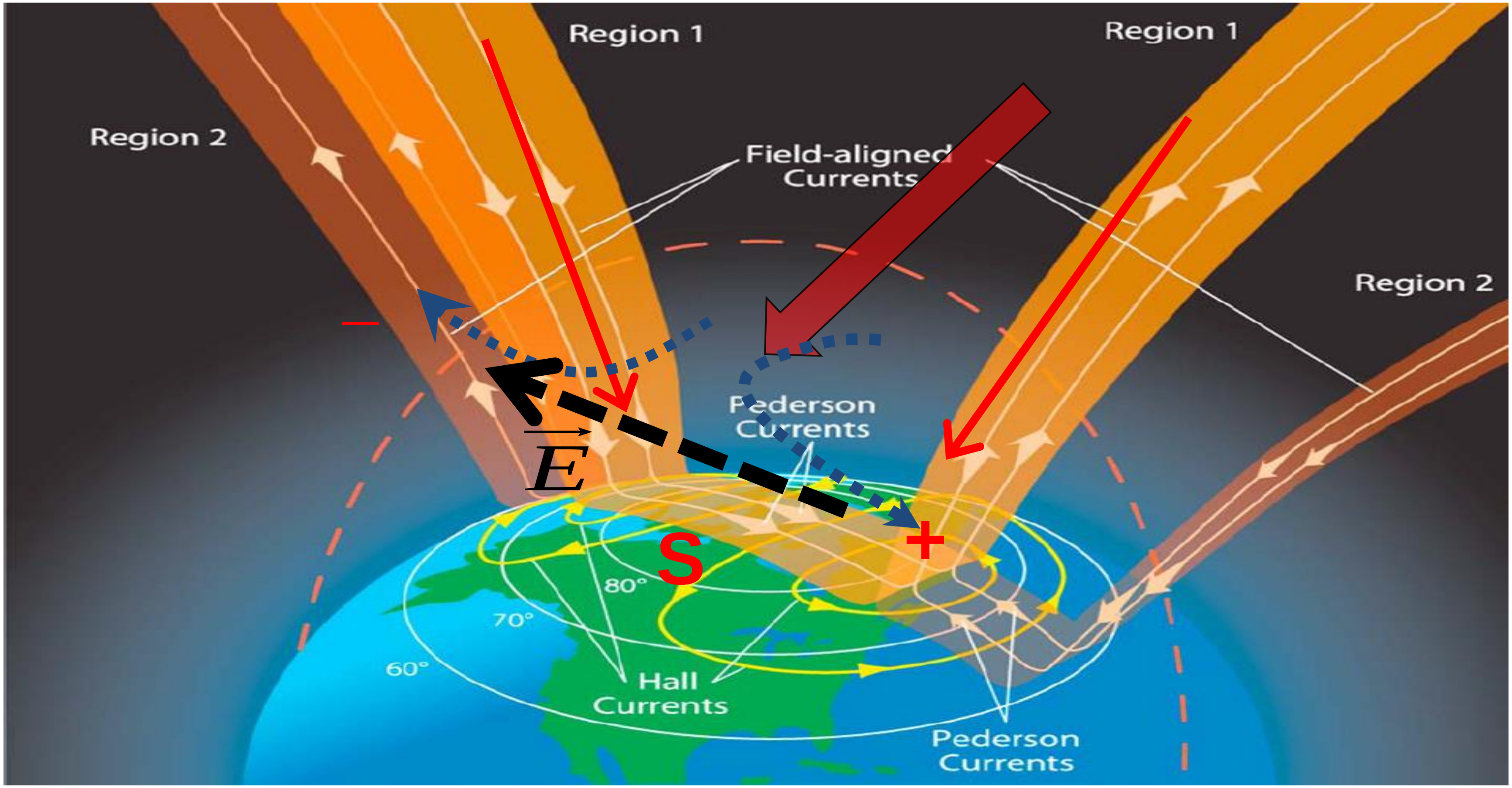


❑ 2000년 7월 14일



*** MHD Dynamo:** $\vec{E} + \vec{V} \times \vec{B} = 0$ ***(ideal MHD eq.)***

- ***EM energy generates mechanical energy or***
- ***Mechanical energy generates EM energy***



Application
- Magnetospheric dynamics

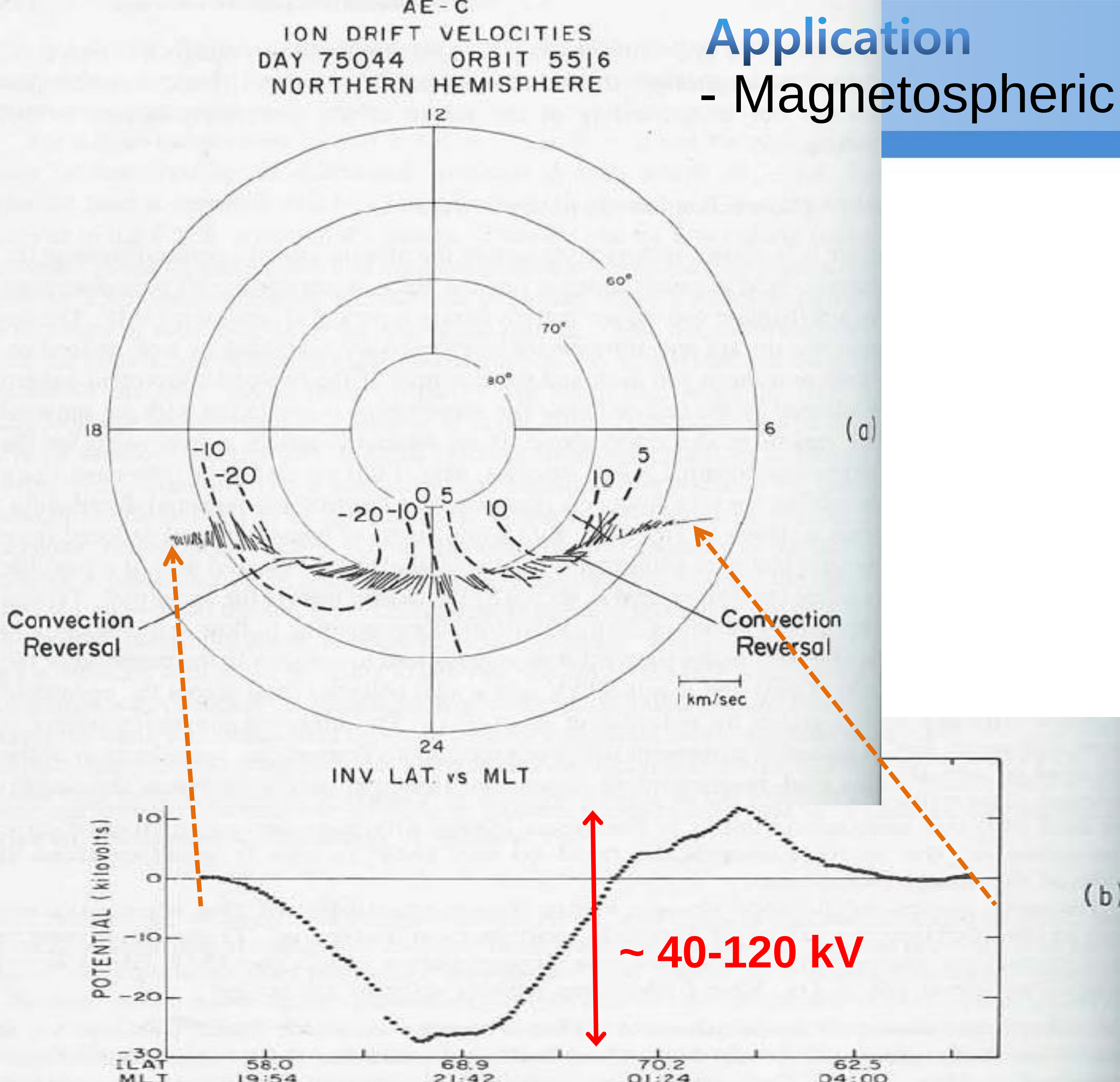
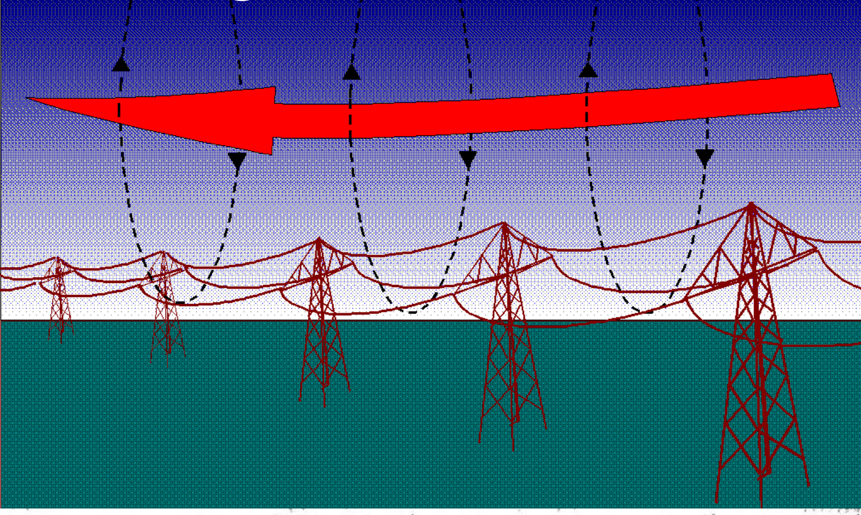
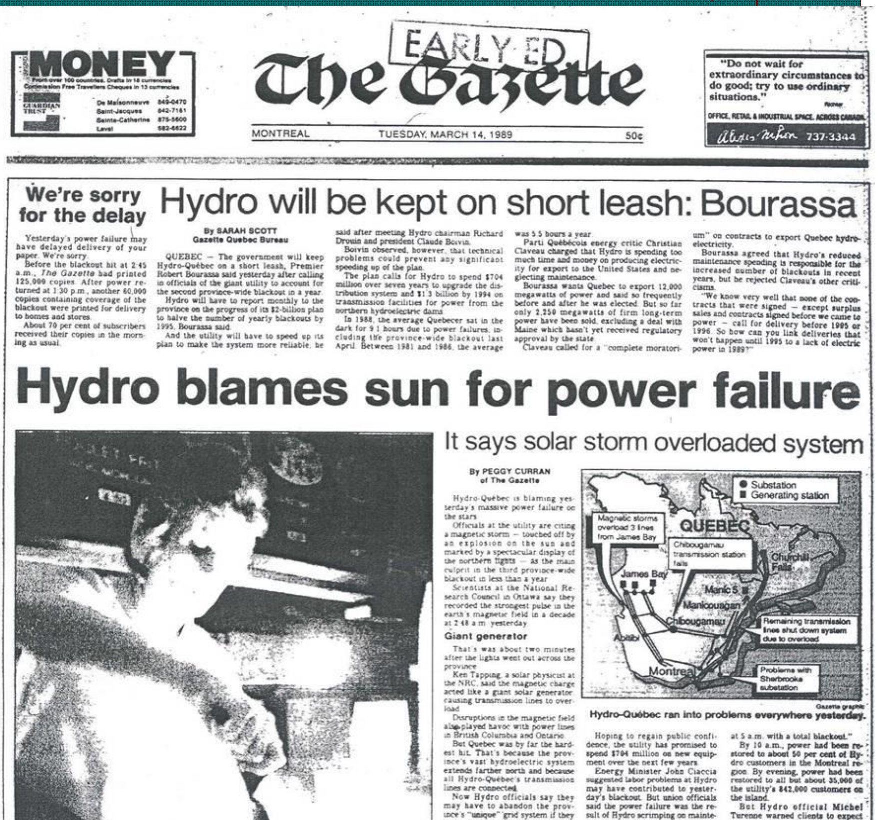


Fig. 6.7. (a) A satellite flight across the high-latitude convection pattern provides drift velocity profiles, which are shown along with the inferred convection pattern. (b) The potential distribution resulting from this convective flow pattern shows maxima and minima at the polar cap boundaries and a total potential difference of about 60 kV across the polar cap. [After Heelis and Hanson (1980). Reproduced with permission of the American Geophysical Union.]

Geomagnetic Induced Currents

1989.3.13





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EARLY ED

The Gazette

MONTREAL TUESDAY, MARCH 14, 1989 50¢

"Do not wait for extraordinary circumstances to do good; try to use ordinary situations."

OFFICE, RETAIL & INDUSTRIAL SPACE ACROSS CANADA 737-3344

We're sorry for the delay

Yesterday's power failure may have delayed delivery of your paper. We're sorry.

Before the blackout hit at 2:45 a.m., *The Gazette* had printed 125,000 copies. After power returned at 1:30 p.m., another 60,000 copies containing coverage of the blackout were printed for delivery to homes and stores.

About 70 per cent of subscribers received their copies in the morning as usual.

Hydro will be kept on short leash: Bourassa

By SARAH SCOTT
Gazette Quebec Bureau

QUEBEC – The government will keep Hydro-Québec on a short leash, Premier Robert Bourassa said yesterday after calling in officials of the giant utility to account for the second province-wide blackout in a year.

Hydro will have to report monthly to the province on the progress of its $2-billion plan to halve the number of yearly blackouts by 1995, Bourassa said.

And the utility will have to speed up its plan to make the system more reliable, he said after meeting Hydro chairman Richard Drouin and president Claude Boivin.

Boivin observed, however, that technical problems could prevent any significant speeding up of the plan.

The plan calls for Hydro to spend $704 million over seven years to upgrade the distribution system and $1.3 billion by 1994 on transmission facilities for power from the northern hydroelectric dams.

In 1988, the average Quebecer sat in the dark for 9.1 hours due to power failures, including the province-wide blackout last April. Between 1981 and 1986, the average was 5.5 hours a year.

Parti Québécois energy critic Christian Claveau charged that Hydro is spending too much time and money on producing electricity for export to the United States and neglecting maintenance.

Bourassa wants Quebec to export 12,000 megawatts of power and said so frequently before and after he was elected. But so far only 2,250 megawatts of firm long-term power have been sold, excluding a deal with Maine which hasn't yet received regulatory approval by the state.

Claveau called for a "complete moratorium" on contracts to export Quebec hydro-electricity.

Bourassa agreed that Hydro's reduced maintenance spending is responsible for the increased number of blackouts in recent years, but he rejected Claveau's other criticisms.

"We know very well that none of the contracts that were signed – except surplus sales and contracts signed before we came to power – call for delivery before 1995 or 1996. So how can you link deliveries that won't happen until 1995 to a lack of electric power in 1989?"

Hydro blames sun for power failure

It says solar storm overloaded system

By PEGGY CURRAN
of The Gazette

Hydro-Québec is blaming yesterday's massive power failure on the stars.

Officials at the utility are citing a magnetic storm – touched off by an explosion on the sun and marked by a spectacular display of the northern lights – as the main culprit in the third province-wide blackout in less than a year.

Scientists at the National Research Council in Ottawa say they recorded the strongest pulse in the earth's magnetic field in a decade at 2:48 a.m. yesterday.

Giant generator

That's was about two minutes after the lights went out across the province.

Ken Tapping, a solar physicist at the NRC, said the magnetic charge acted like a giant solar generator causing transmission lines to overload.

Disruptions in the magnetic field also played havoc with power lines in British Columbia and Ontario.

But Quebec was by far the hardest hit. That's because the province's vast hydroelectric system extends farther north and because all Hydro-Québec's transmission lines are connected.

Now Hydro officials say they may have to abandon the province's "unique" grid system if they

Gazette graphic

Hydro-Québec ran into problems everywhere yesterday.

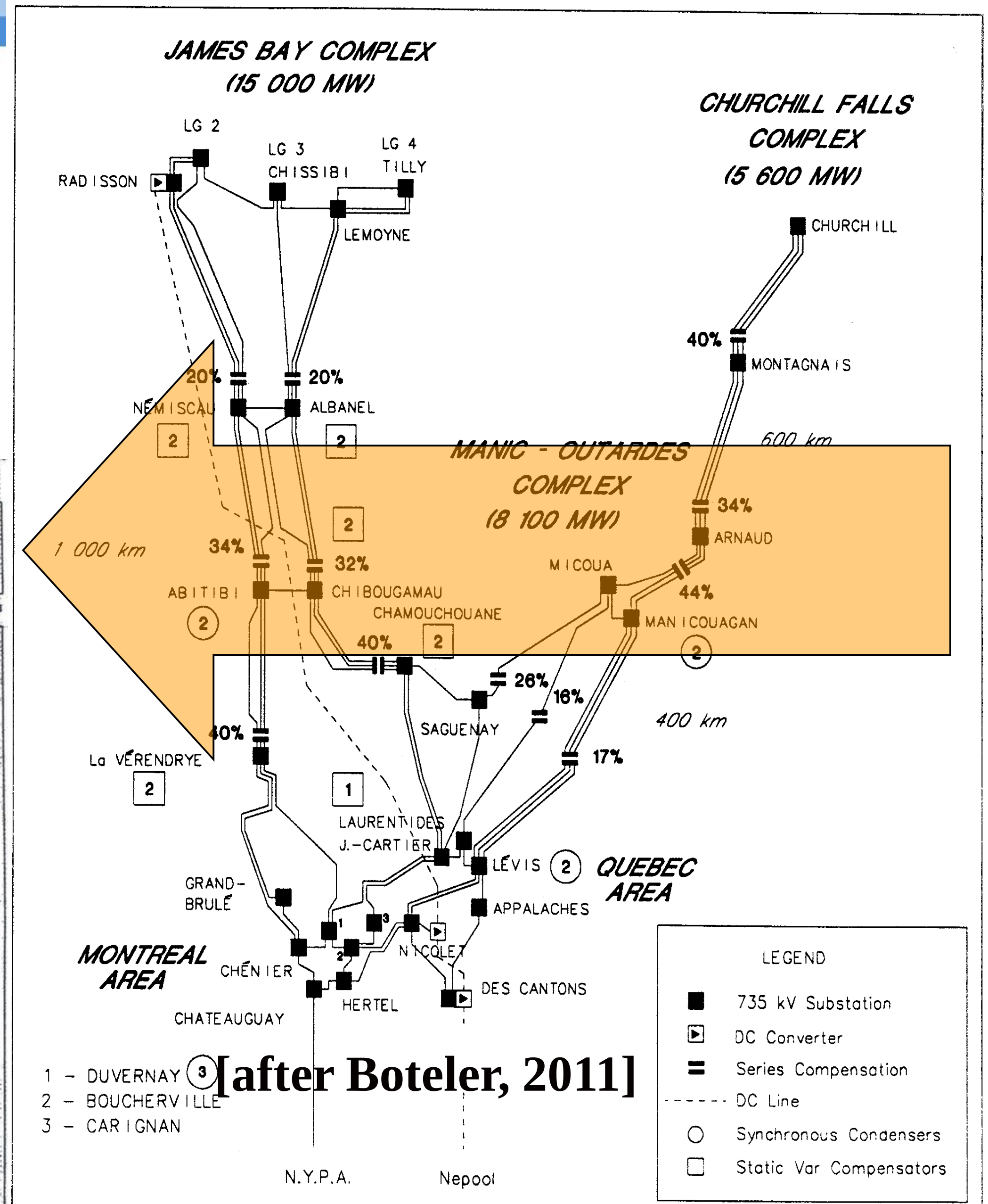
Hoping to regain public confidence, the utility has promised to spend $704 million on new equipment over the next few years.

Energy Minister John Ciaccia suggested labor problems at Hydro may have contributed to yesterday's blackout. But union officials said the power failure was the result of Hydro scrimping on mainte-

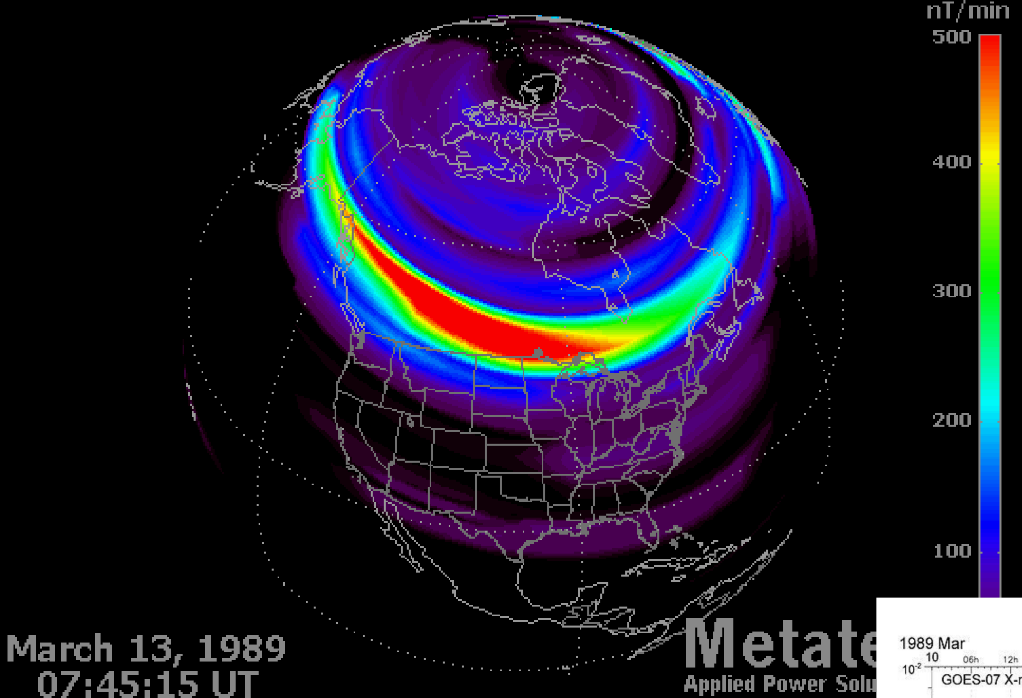
at 5 a.m. with a total blackout."

By 10 a.m., power had been restored to about 50 per cent of Hydro customers in the Montreal region. By evening, power had been restored to all but about 35,000 of the utility's 842,000 customers on the island.

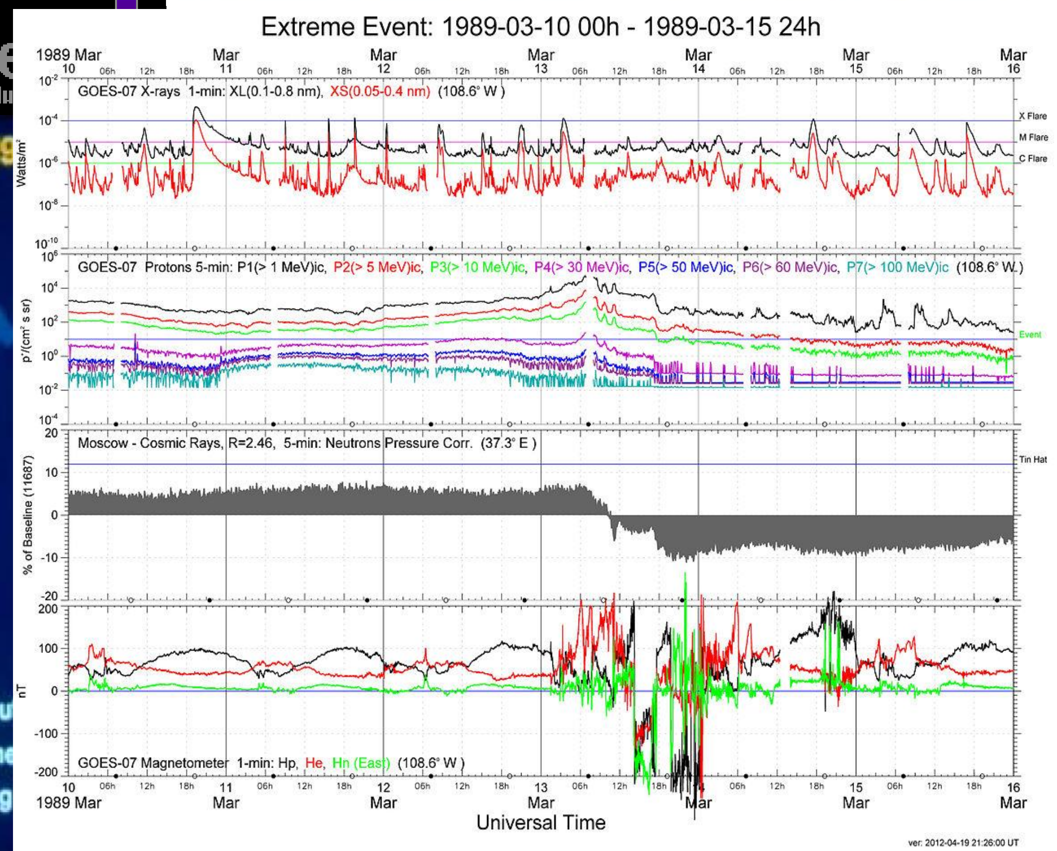
But Hydro official Michel Turenne warned clients to expect



[after Boteler, 2011]

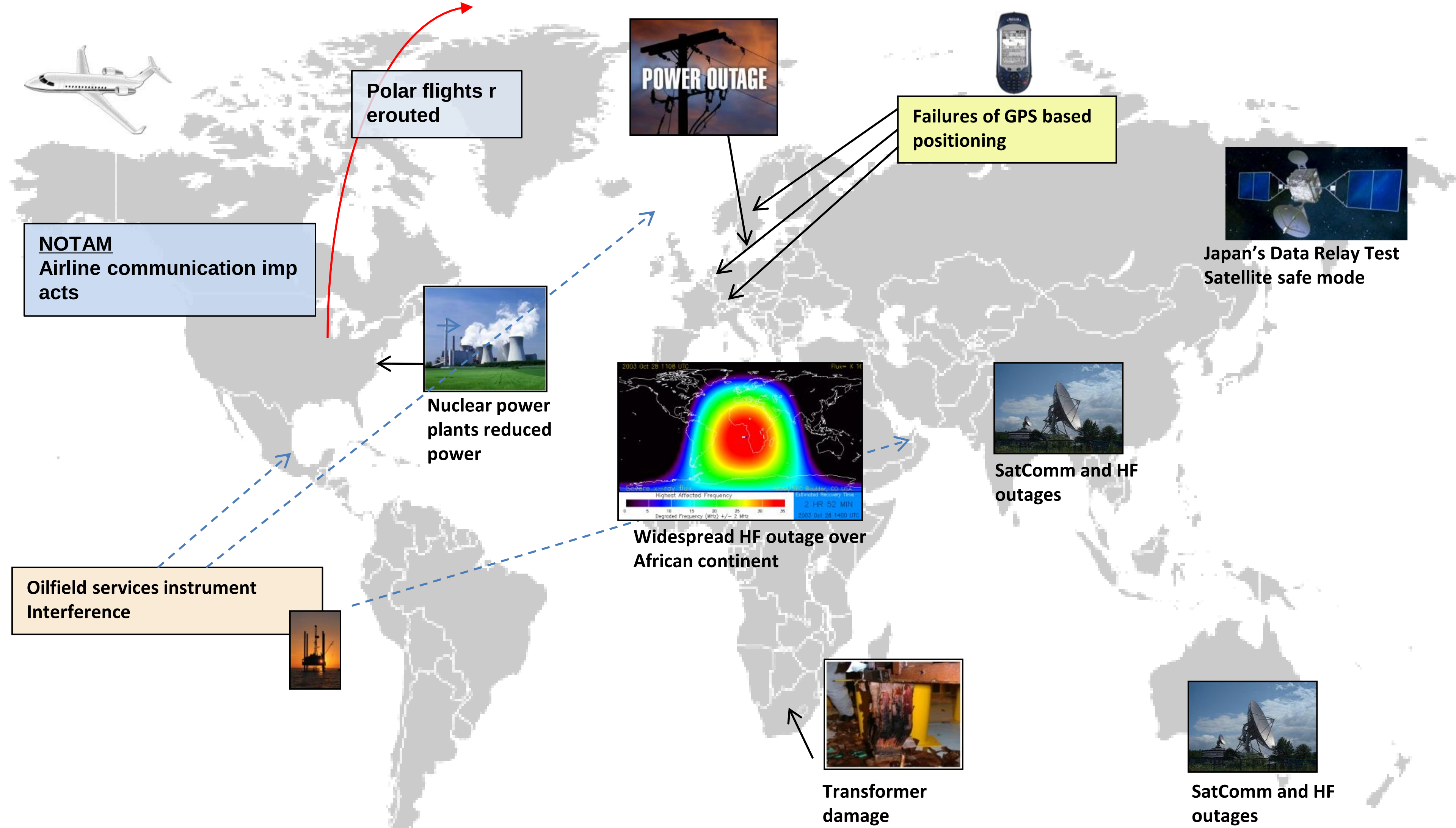

nT/min
500
400
300
200
100
March 13, 1989
07:45:15 UT
Metate
Applied Power Solu


POWER SYSTEM EVENTS DUE TO SMD MARCH 13, 19
B = Blackou
D = Equipme
T = Tripping


Extreme Event: 1989-03-10 00h - 1989-03-15 24h
GOES-07 X-rays 1-min: XL(0.1-0.8 nm), XS(0.05-0.4 nm) (108.6° W)
X Flare
M Flare
C Flare
Watts/m²
GOES-07 Protons 5-min: P1(> 1 MeV)ic, P2(> 5 MeV)ic, P3(> 10 MeV)ic, P4(> 30 MeV)ic, P5(> 50 MeV)ic, P6(> 60 MeV)ic, P7(> 100 MeV)ic (108.6° W)
Event
Moscow - Cosmic Rays, R=2.46, 5-min: Neutrons Pressure Corr. (37.3° E)
Tin Hat
% of Baseline (11687)
GOES-07 Magnetometer 1-min: Hp, He, Hn (East) (108.6° W)
nT
1989 Mar
Universal Time
ver: 2012-04-19 21:26:00 UT

Space Weather: Global feature

Reported impacts from a storm in October, 2003



Over 130 hours of HF communication blackout in Anarctic

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- China (Beijing)
- Czech Republic (Prague)
- India (New Delhi)
- Japan (Tokyo)

http://www.spaceweather.org/

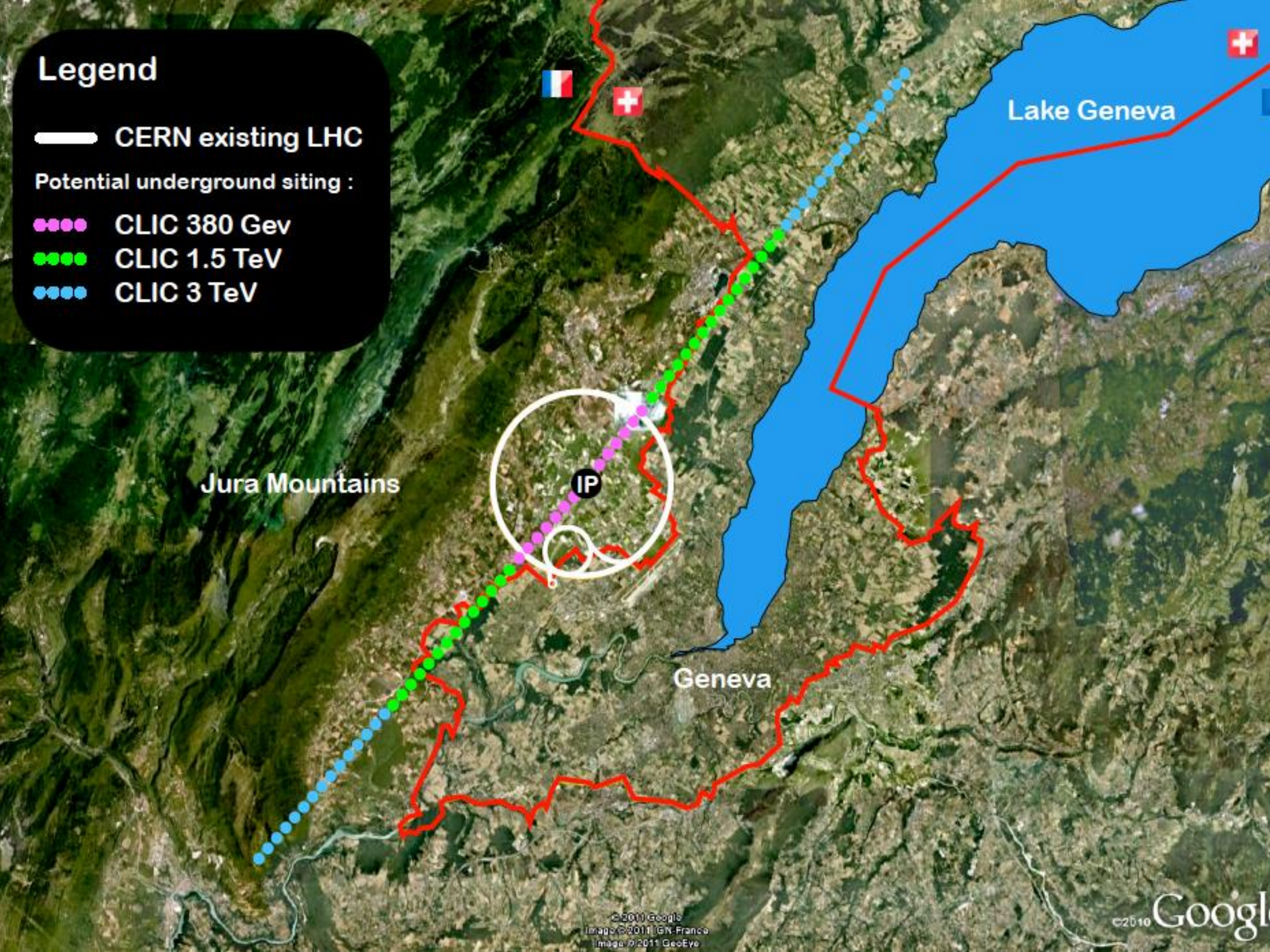
Summary

- The near-Earth space provides a broad range of temporal and spatial phenomena from single-ptl to MHD, which can be confirmed in *in situ* observations.

- MHD disturbances & waves tend to effectively affect geomagnetic variations in the sense that relatively large-scale EM variations occur with considerable amplitude.

- In terms of spatial and temporal scales over CLIC's criterion, it seems that natural sources from "Space" such as dB~nT over dT~1 sec can be well incorporated (Space Weather should be monitored, though).

- In addition, local conductivity variation should be checked in advance by comparing B(t) at the two "Ground" ends.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CERN existing LHC
Potential underground siting :
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CLIC 1.5 TeV
CLIC 3 TeV
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