"Osservazioni elettromagnetiche e gravimetriche relative al sisma del 6 Aprile 2009 a L'Aquila"

ULF Signals of External Origin

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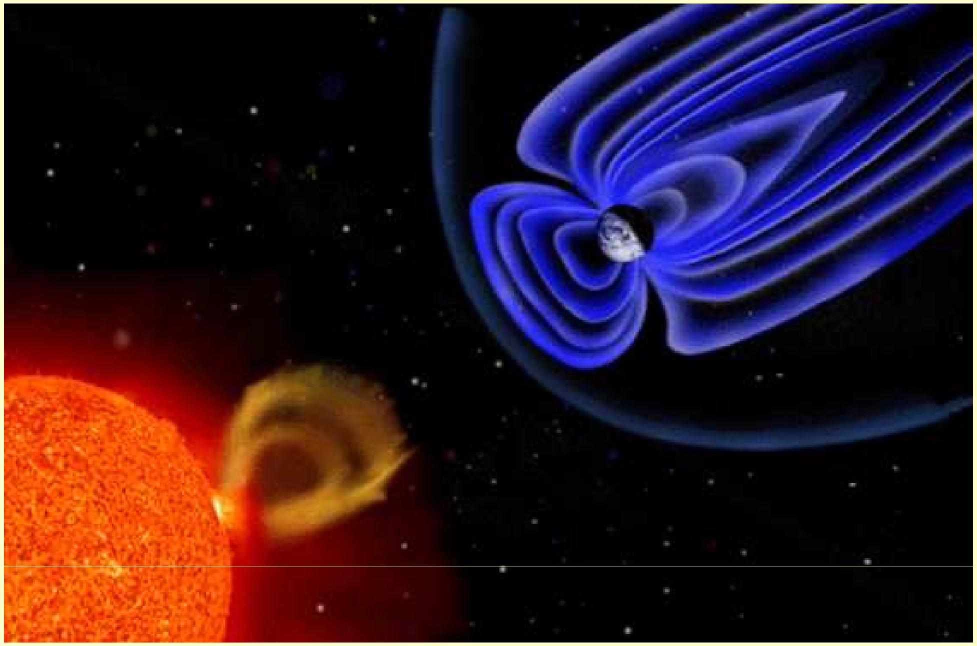
L'Aquila, 26-28 Aprile 2010.

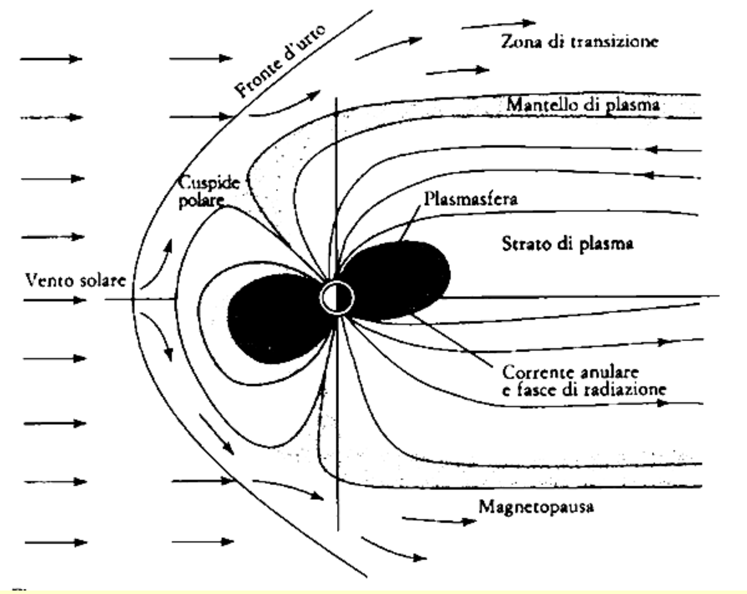
Earthquake precursors in the ULF range (1 mHz-1Hz) ?

- A substantial increase in the noise background starting from days to several weeks preceding earthquake.
- An increase to a high level of activity in the range ≈10-50 mHz starting few hours before the earthquake.
- A broad maximum of the "polarization parameter" $R=P_z/P_H$ about one month before the earthquake (P_Z and P_H being the integrated power in the vertical and horizontal component, respectively).
- A gradual decrease of the slope of the power spectrum during the process of earthquake preparation (1-1.5 month).
- An increased occurrence of negative or positive pulses of short duration on the East/West component (D).

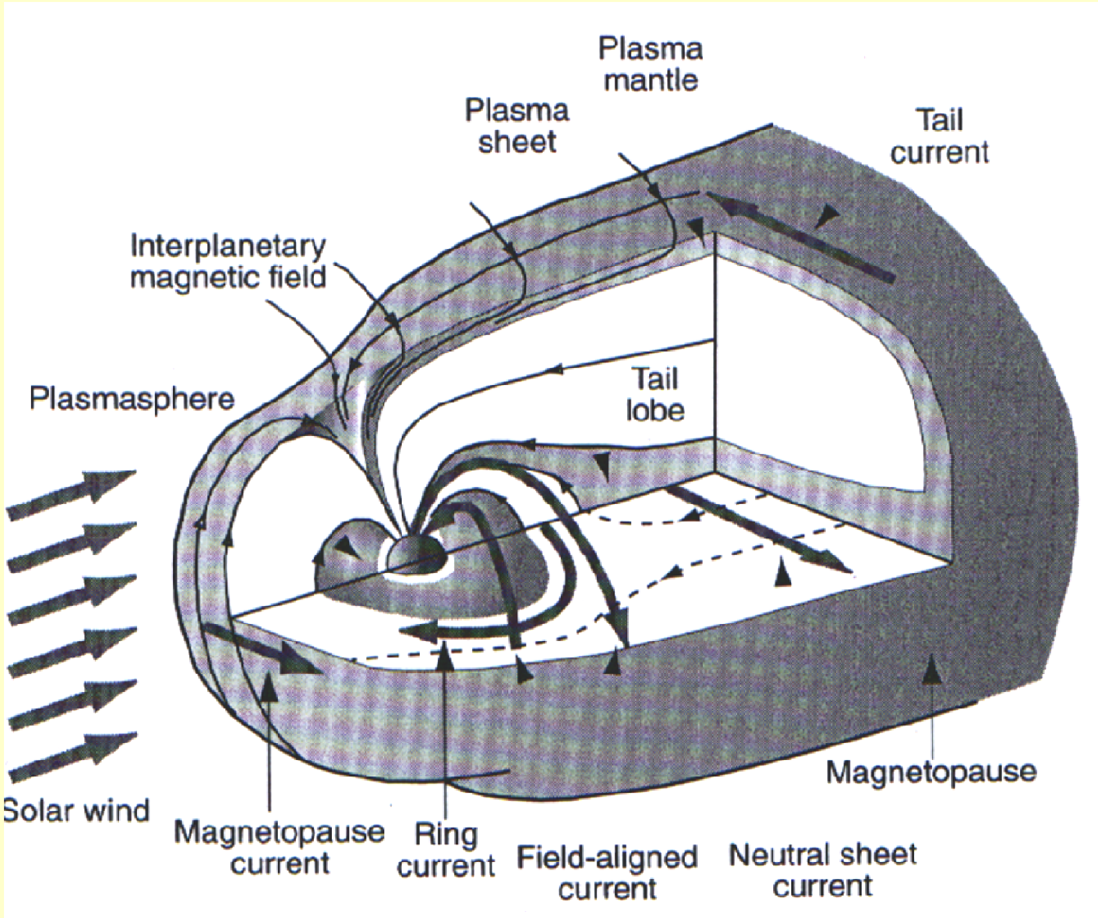
A large variety of ULF signals (often neglected) come from the interplanetary space and the magnetosphere.

The Earth's Magnetosphere



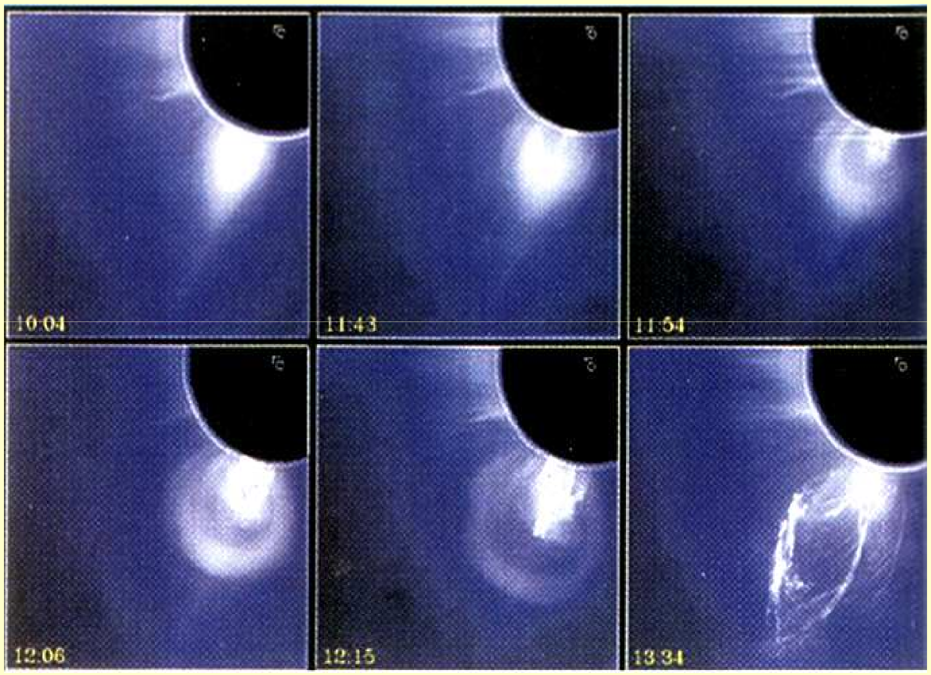


The tridimensional magnetosphere

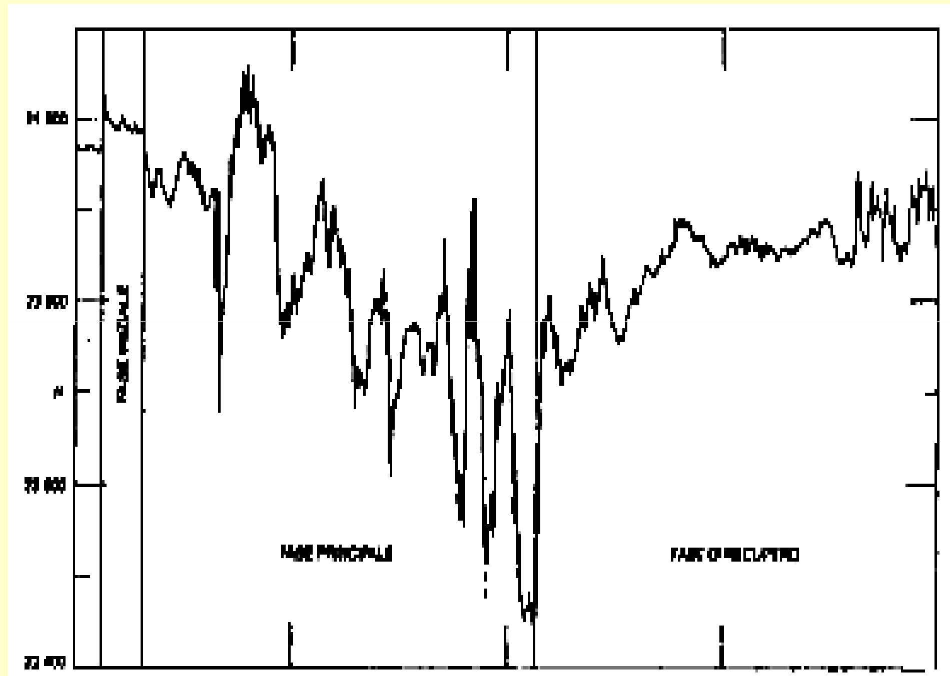


- Major geomagnetic variations are manifestations of magnetospheric and ionospheric current systems.

Coronal mass ejections (CME)



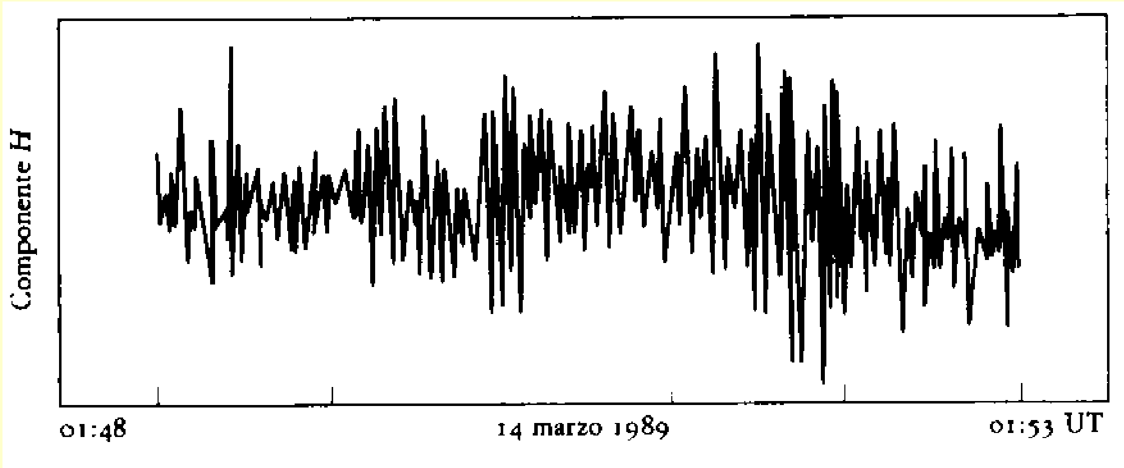
Magnetic storms

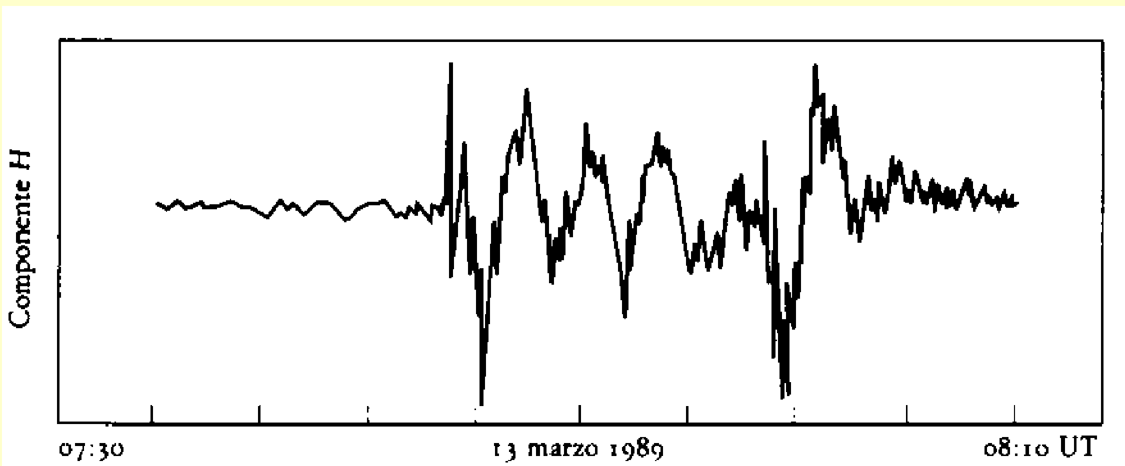


13 marzo 1989 **14 marzo 1989**

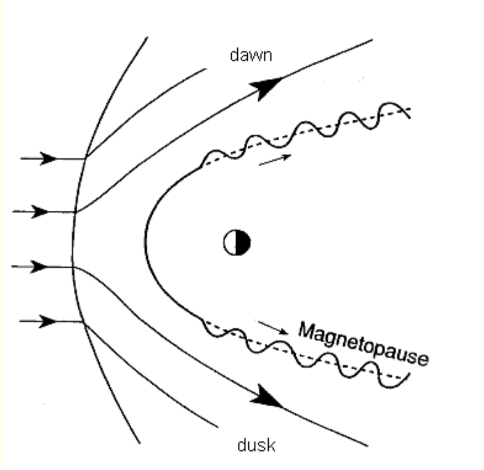
L'Aquila Observatory

ULF signals at ground

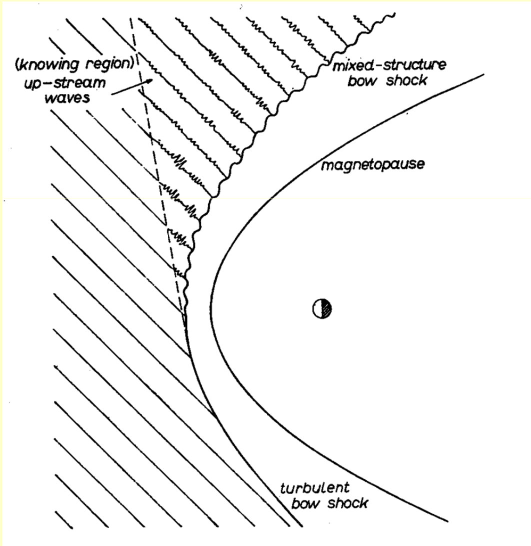




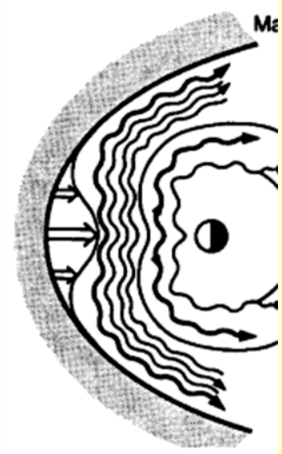
ULF Signals of external origin



KHI of the magnetopause
(f~1-20 mHz).



Penetration of “upstream waves” from the foreshock region (f~20-100 mHz).

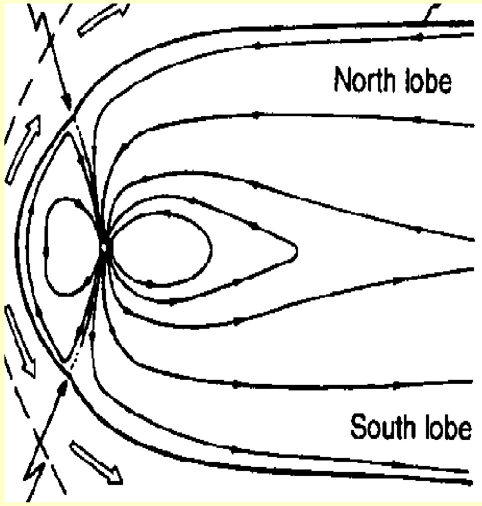


Waves at “discrete” frequencies
(f~1.3, 1.9, 2.4, 3.3,…mHz).

Field line eigenfrequencies and resonance processes

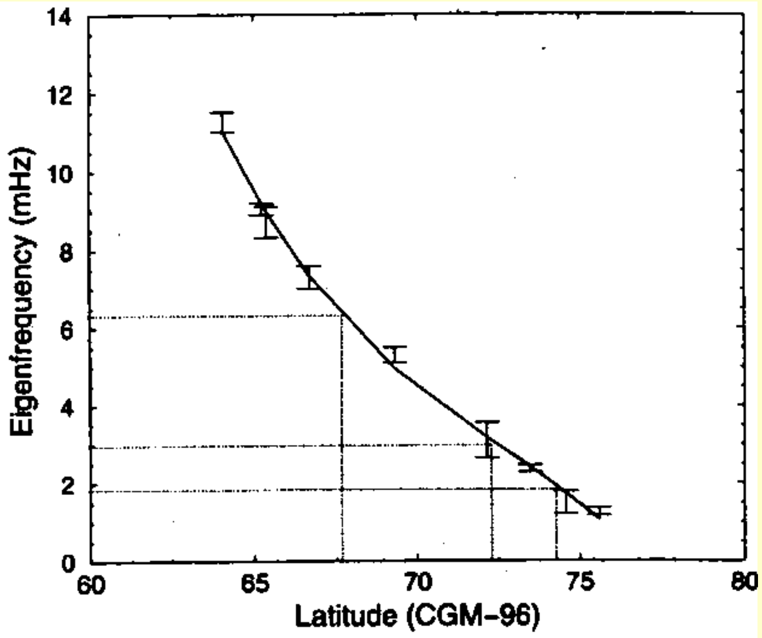
$$T_n = \frac{2}{n}\int_1 \frac{ds}{V_a} \qquad n=1, 2, ..$$

$$T_n = \frac{16\pi R_E^4}{nM\mu_0^{1/2}\cos^8\lambda_0}\int_0^{\lambda_0} \rho^{1/2}\cos^7\lambda \, d\lambda$$

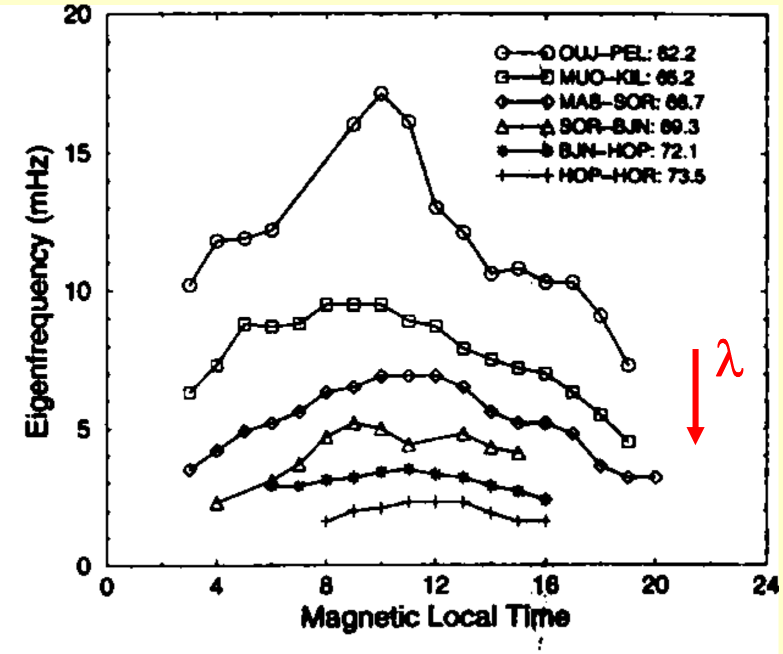


M = dipole moment, λ_0 = latitude of the foot of the line of force.

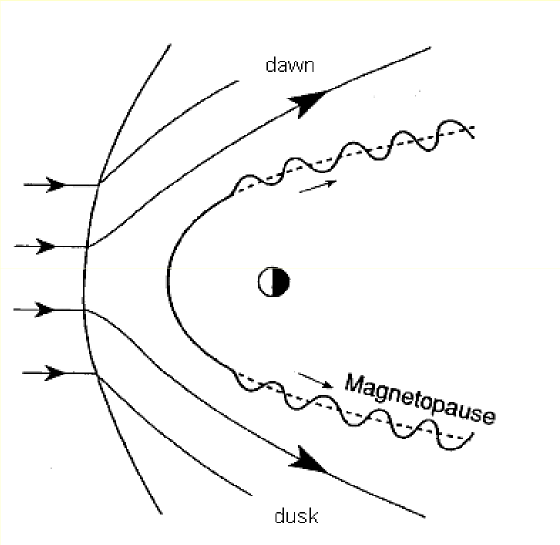
Eigenfr. vs. latitude



Eigenfr. vs. local time

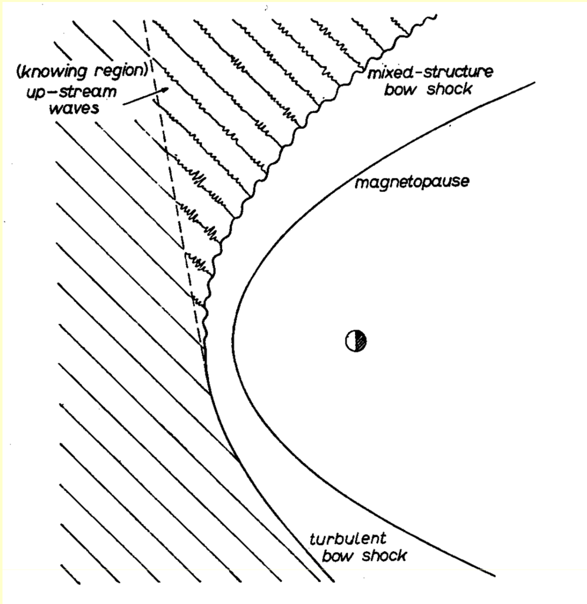


Kelvin-Helmholtz instability of the magnetopause flanks.

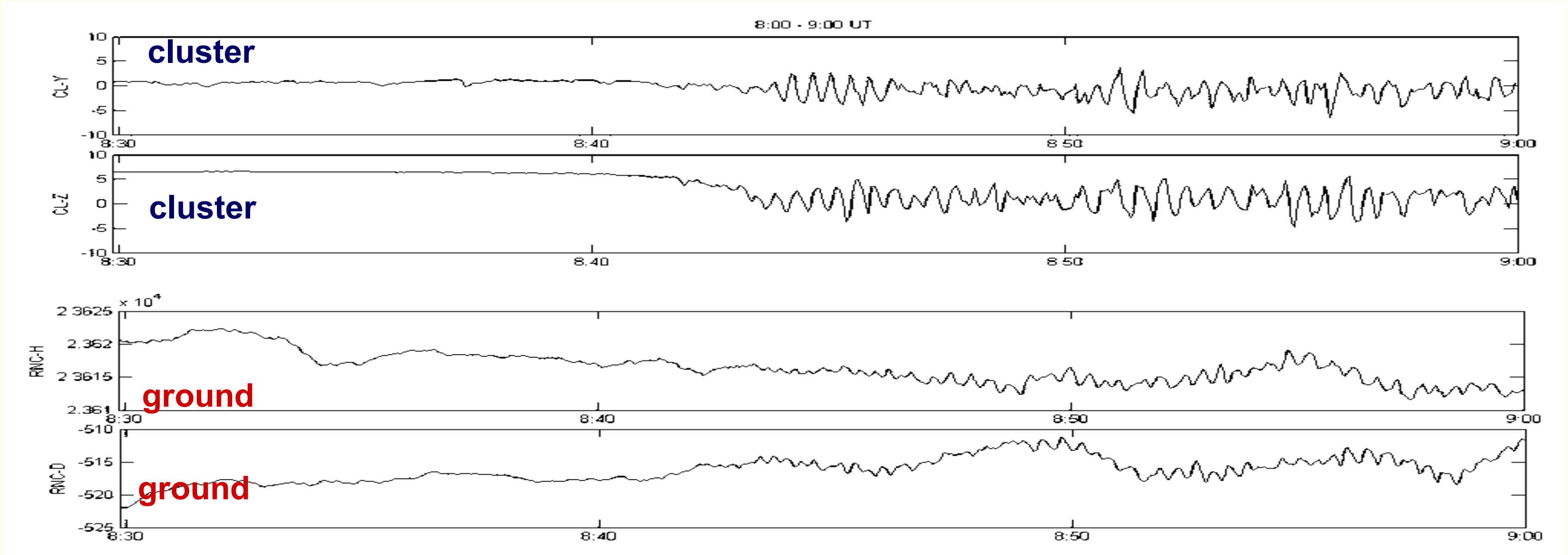


- Surface waves at the magnetopause.
- Driven by high velocity solar wind streams.
- f ~ 1-20 mHz.
- Downstream propagation: polarization reversal across noon.

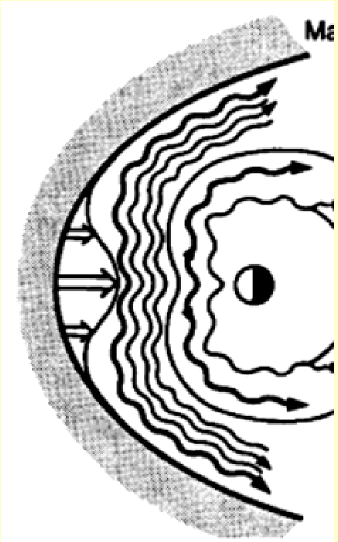
Penetration of "upstream waves" from the foreshock region.



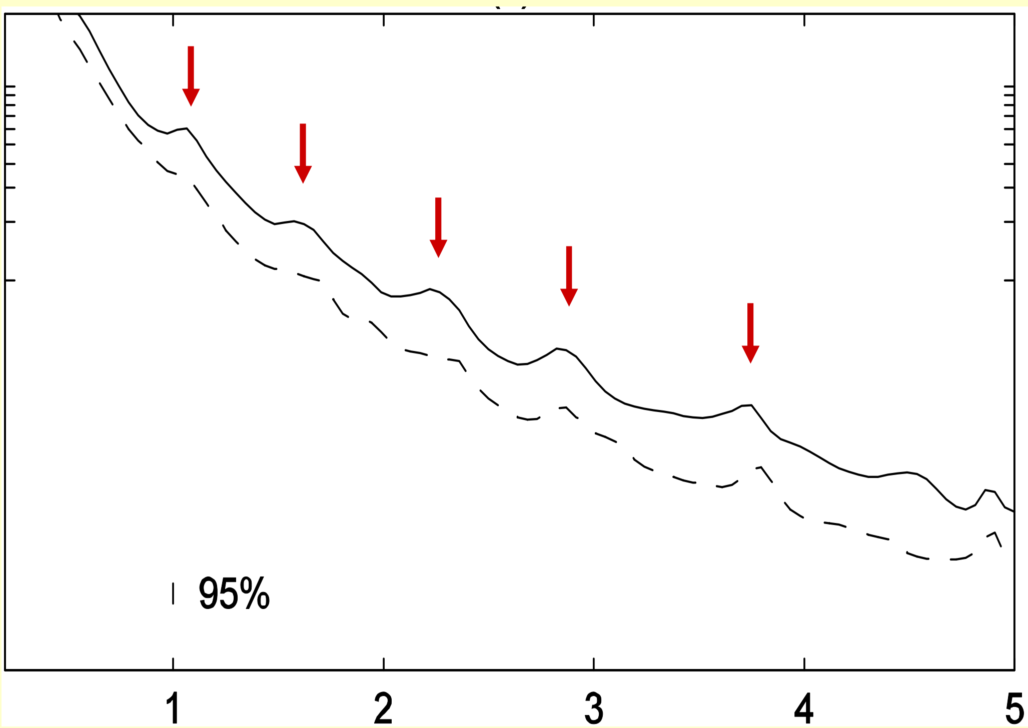
- Ion-cyclotron instability of reflected protons.
- f (mHz) ~ 6B (nT).
- f ~ 20-100 mHz.
- Given the spiral orientation of the IMF, mostly expected in the prenoon quadrant.



Waves at "discrete" frequencies.

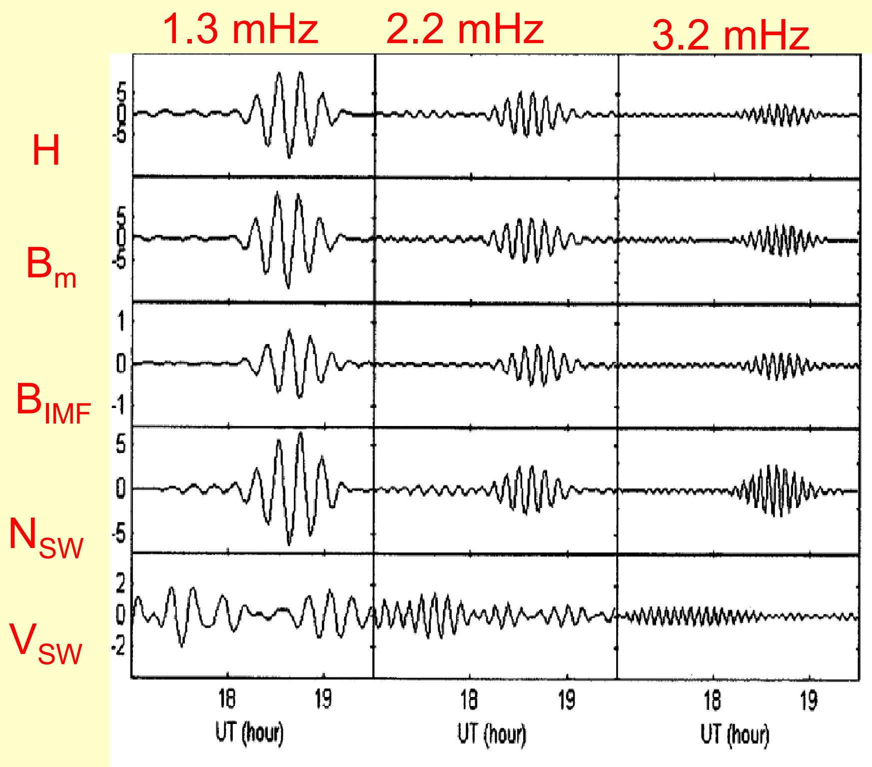


- Global modes of the magnetosphere, driven by SW pressure pulses.
- Same frequencies at different stations (~1.3, 1.9, 2.4, 3.3,… mHz) + local field line resonance.
- Frequencies determined by the position of reflecting boundaries (bow shock, magnetopause, plasmapause, ionosphere, etc.).



AQ observations

Case study



- One-to-one correspondence in H, B_m and N_{sw} (onset, amplitude modulation and duration) of each wave packet.

- No correspondence with $V_{sw.}$

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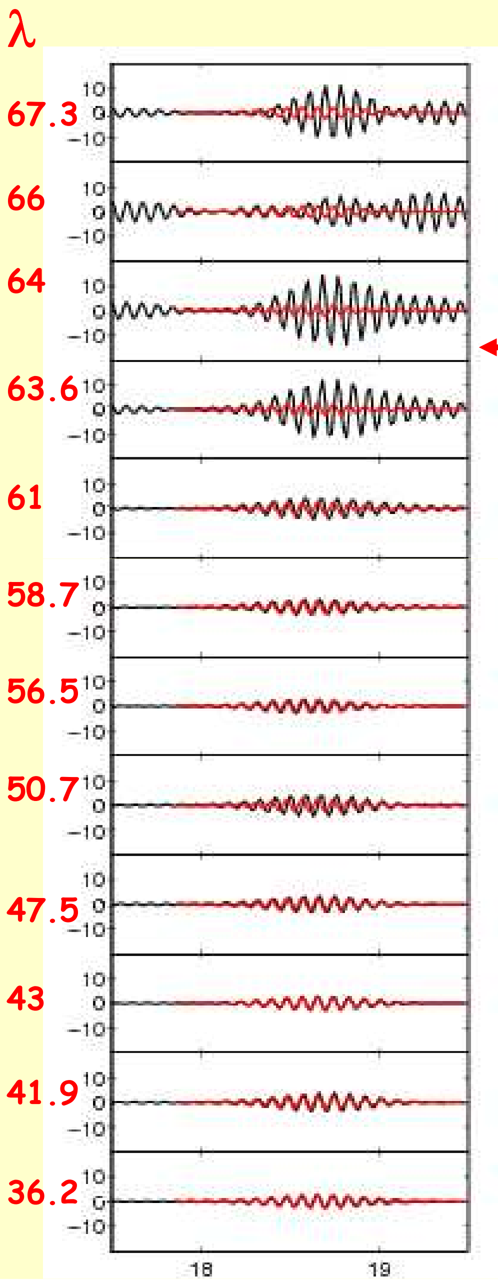
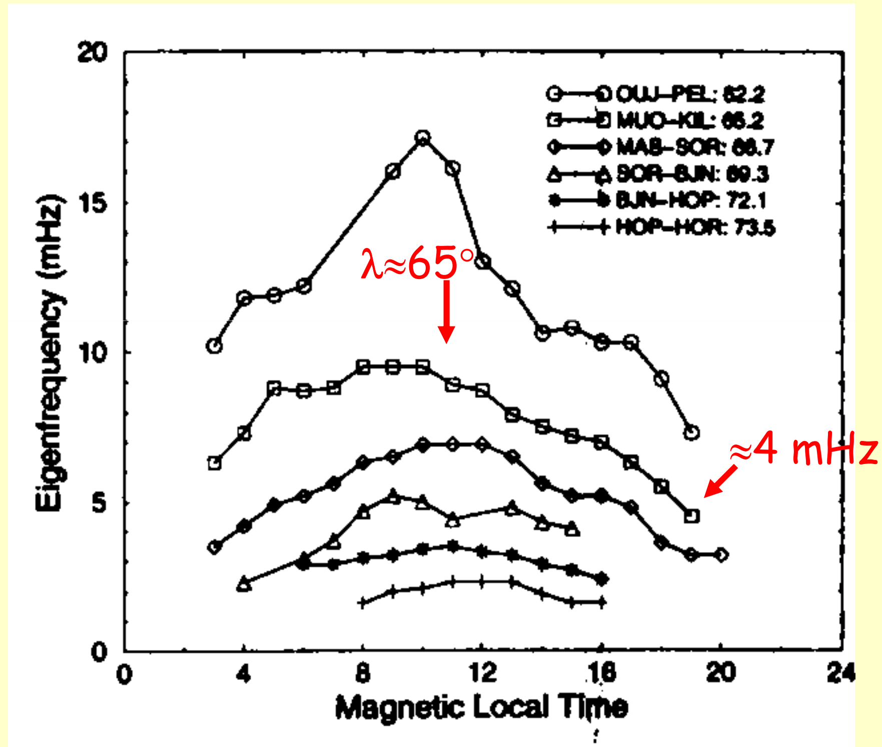
Magnetospheric and ground pulsations at "discrete" frequencies driven by fluctuations of the solar wind density/pressure.

A comparison between predicted and observed waveforms

Mode at f = 3.2 mHz



FLR at λ≈64° in the evening sector



Eigenfrequency vs. time

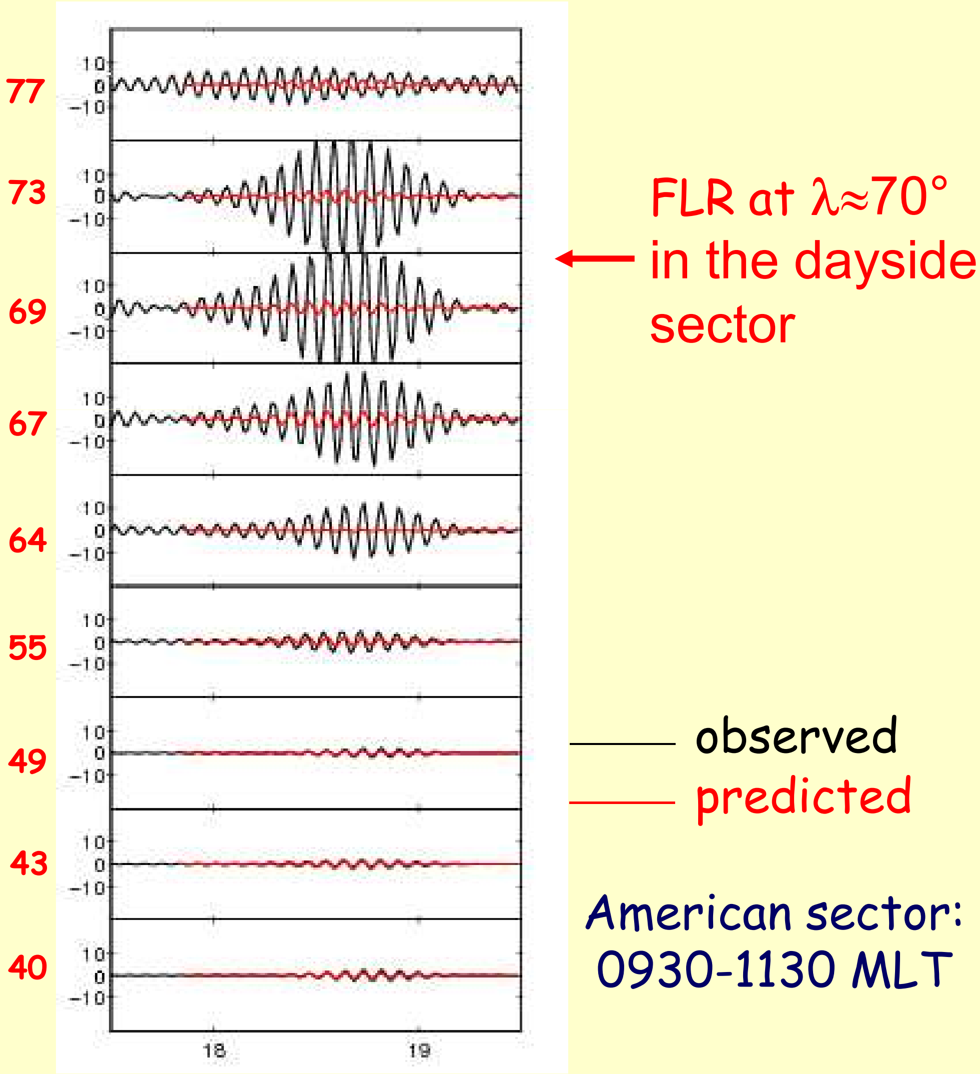
—— observed

—— predicted

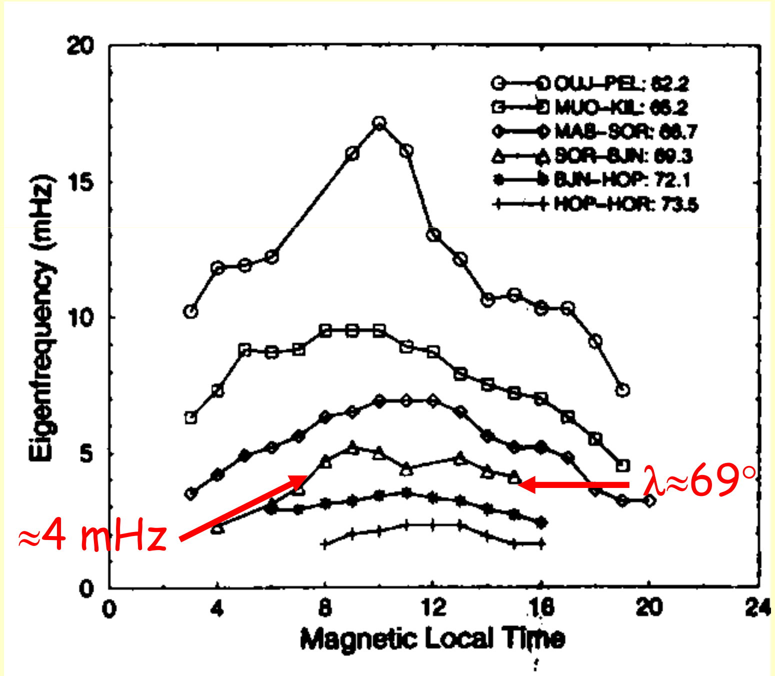
European sector:
19-21 MLT

A comparison between predicted and observed waveforms

Mode at f = 3.2 mHz

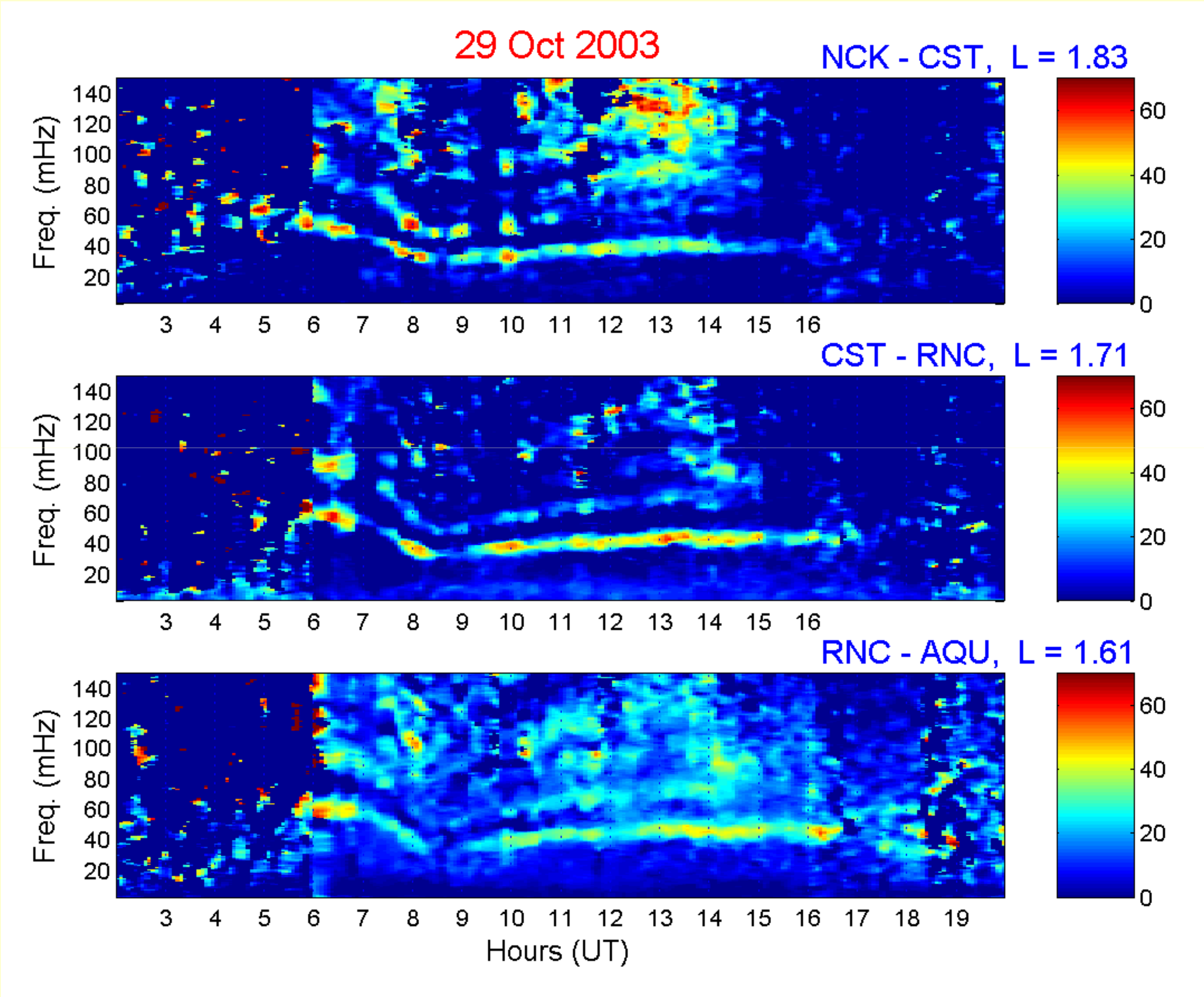


American sector: 0930-1130 MLT



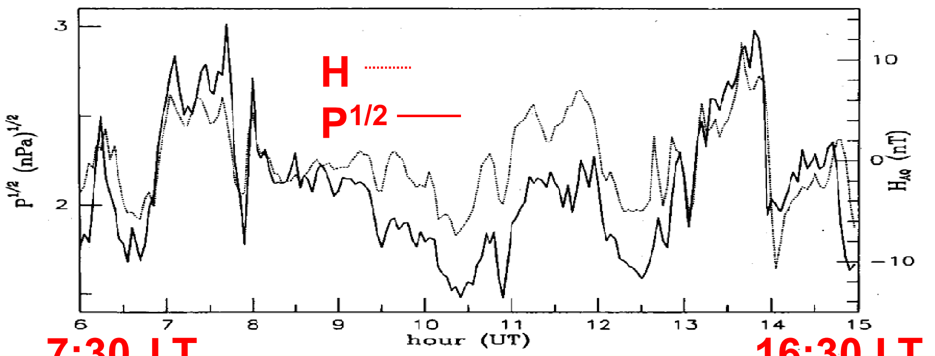
Eigenfrequency vs. time

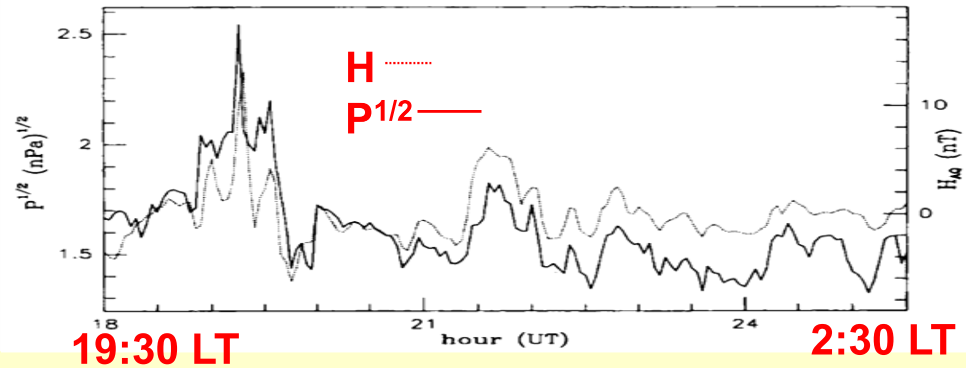
An example of multiple harmonics detection



f_R (midday)	f_2 / f_1
36 mHz	~ 1.6
40 mHz	~ 1.5
43 mHz	~ 1.4

The spectacular correspondence between H and SW pressure (P)



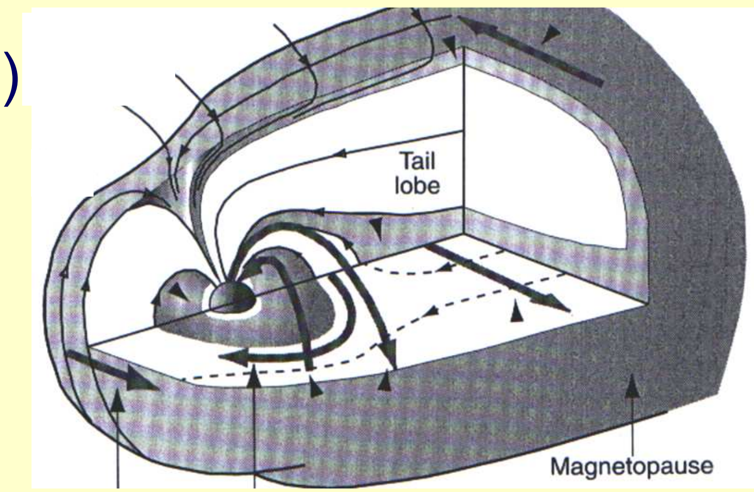


- During quiet conditions, on timescale of minutes, the H-trace closely reflects the $DP^{1/2}$-trace, both in the dayside and nightside.

- Modulation of the magnetopause current.

- The geomagnetic response (i.e. $DH/DP^{1/2}$) has a latitudinal and LT dependence.

Magnetopause current



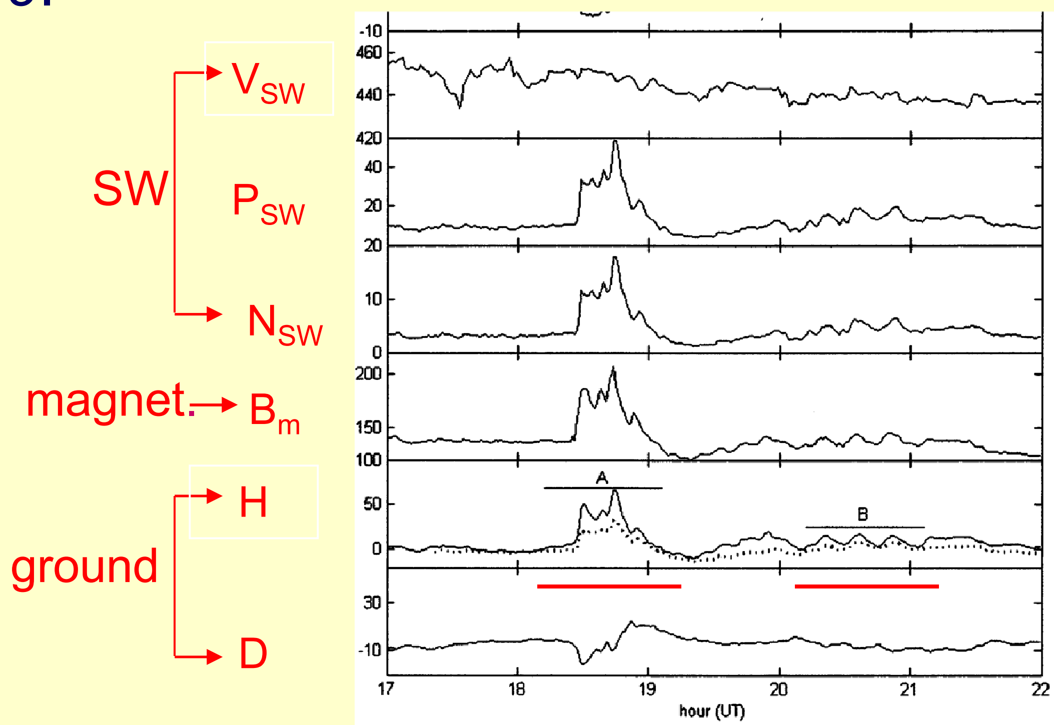
A case study: ground observations at L'Aquila

- Very quiet magnetosphere.
- Same behavior in H, B_m and N_{sw}.
- Strong corr: r ($\Delta P^{1/2}$ vs. ΔH) ≈.99.
- No correlation with SW speed.

- Case A: remarkable variation with superimposed fluctuations.

- Case B: regular fluctuations.

(Villante et al., JGR, 2007)



Aug. 1, 1998.

Conclusions

In the ULF range, candidates for precursory signatures of earthquakes have been proposed in:

- the increase in the noise background and polarization parameter;
- the changing characteristics of the slope of the power spectrum and fractal dimension;
- the possible occurrence of short duration pulses.

The real identification of such precursory aspects (and their statistical significance), requests a careful analysis in terms of:

- contamination from other natural sources and man-made disturbances;
- relationship between the local ULF power and the global geomagnetic activity (Kp and other indices; daily, 27-day, annual and solar-cycle modulation of ULF manifestations of external and magnetospheric origin);
- comparison between ground and space observations (for single events) to ascertain the possible penetration of external waves into the magnetosphere.

Conclusions

In addition, the possible identification of earthquake related ULF signals (if any) is remarkably influenced by other factors such as:

- the strength of the earthquake,
- the distance of the geomagnetic measurements from the epicentre,
- the depth of the hypocenter,
- the local electrical conductivity of the Earth's crust.

The expected ULF disturbances related to earthquakes (if any) are generally weak and sophisticated signal processing methods and a lot of experience are required to evaluate the source of ULF emission.

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The availability of ULF (and other) measurements from several stations and the concurring contributions of different expertises provide a unique opportunity for a careful investigation of these aspects for the L'Aquila earthquake.

GRAZIE

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