Geospace Workshop - Rhodes Island, Greece, Sept. 2014

Plasma wave modes observed by Cluster and their possible role in radiation belt dynamics

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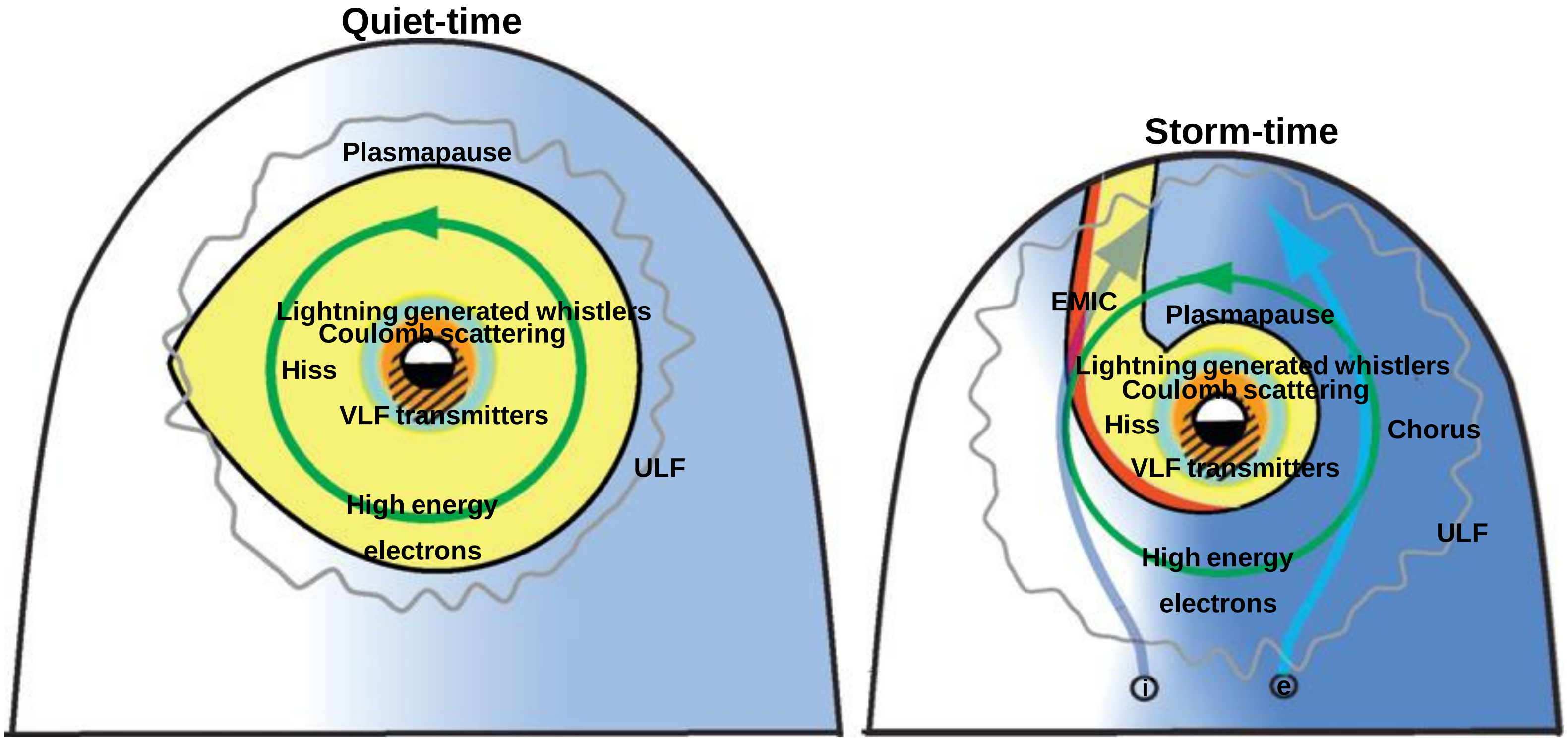
Wave - particle interactions in outer radiation belts: overview



Acceleration and loss processes as summarized by Shprits et al., JASTP, 2008

Prior to RBSP: complex yet incomplete picture of the acceleration mechanisms.

RBSP provides strong evidences for the local acceleration (e.g., Reeves et al., 2013).

Need to identify dominant mechanism(s) for specific storm conditions.

Other WPI mechanisms could be involved:

- magnetosonic waves, bounce resonances (Roberts & Schulz, 1968; Horne et al., 2007);
- ULF waves, drift and drift-bounce resonances (Southwood et al., 1969; Mann et al., 2013);
- large-amplitude whistlers, double layers (Catell et al., 2008; Mozer et al., 2013).

Types of emissions in ELF-VLF frequency range

Equatorial magnetosonic waves (MSW):

- linearly polarize compressional mode waves;
- observed between local f_{cH} and local f_{LH};
- maximum magnitudes in post-noon sector.

Plasmaspheric hiss:

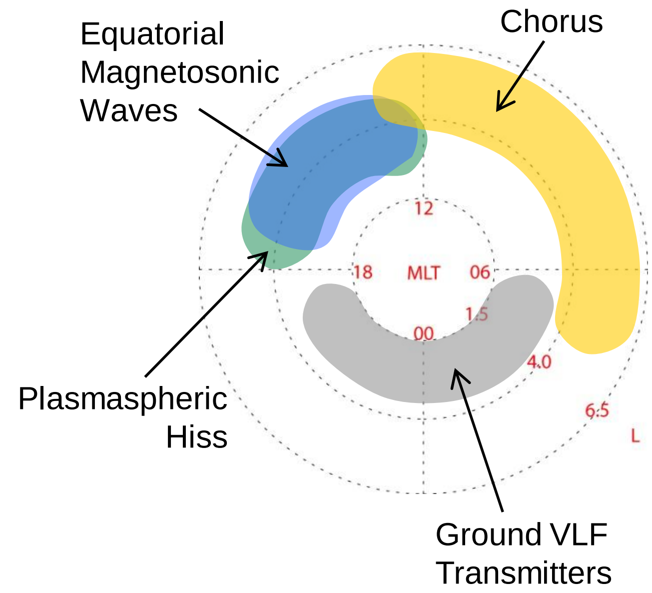
- incoherent whistler-mode (RH-polarized) waves;
- observed at frequencies ~100Hz - 3 kHz at all MLT values;
- maximum magnitudes in the post-noon/evening sector.

Chorus:

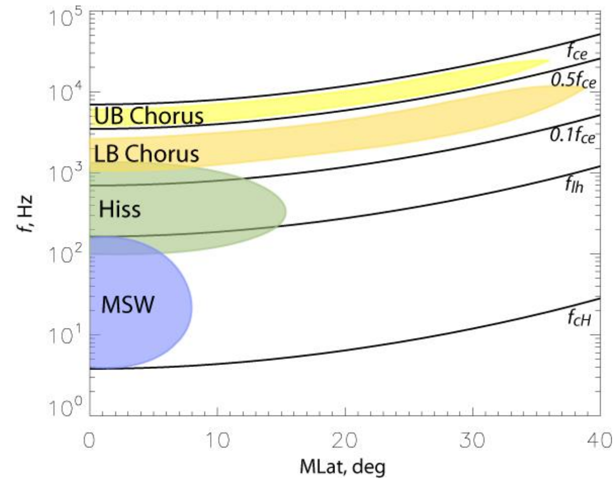
- coherent whistler-mode waves;
- observed at frequencies 0.1 - 0.8 f_{ce} (~ 2 - 6 kHz), often in two frequency bands below and above 0.5 f_{ce};
- appear in dawn-midday sector near and outside plasmapause;
- often could not be distinguished from hiss emissions.

Ground VLF transmitters:

- signatures of ground-based VLF transmitters observed at ~ 10 - 50 kHz;
- appear at night times, i.e. when the ionosphere is not dense enough.

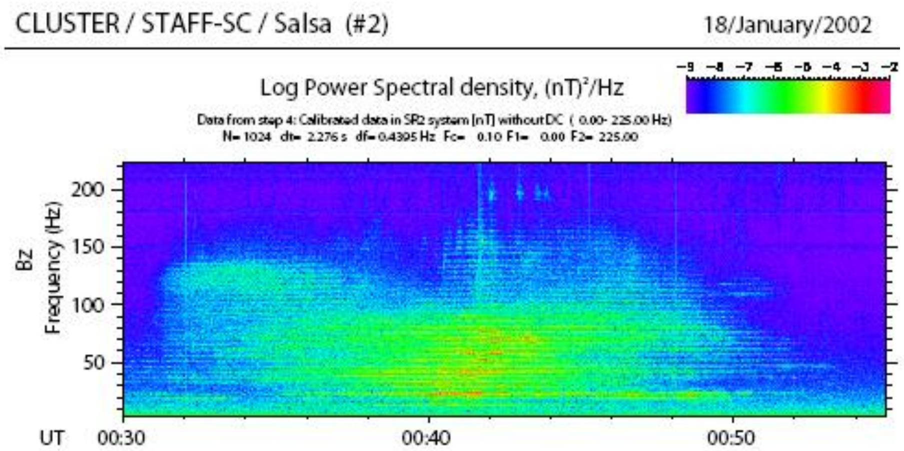


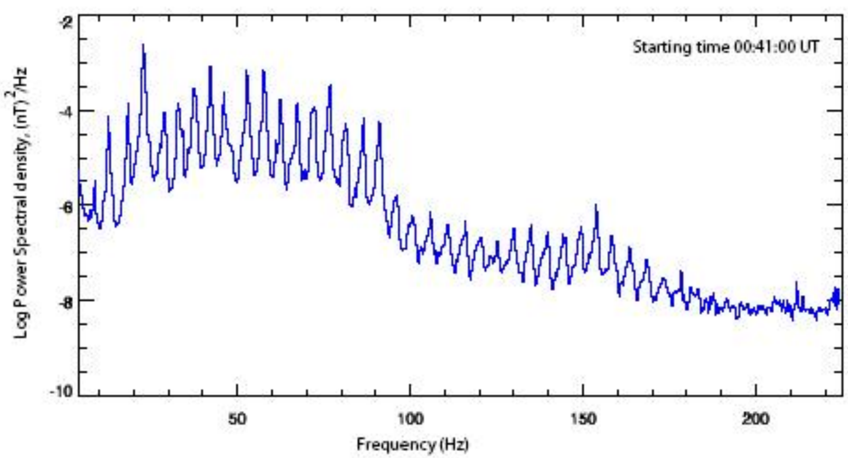
Schematic distribution of various types of electromagnetic emissions

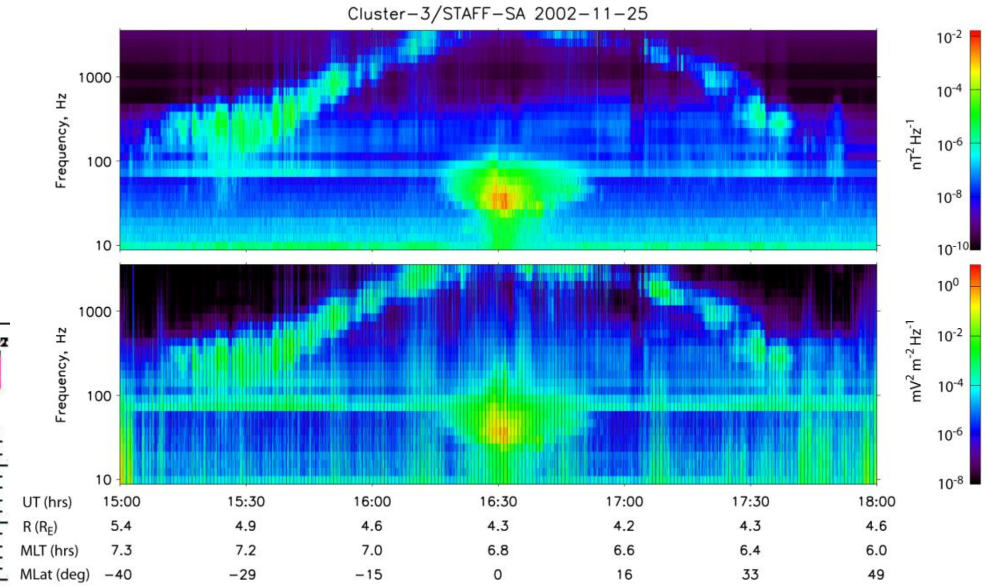


Equatorial MSWs near harmonics of f_{H^+}

Intense magnetosonic emissions are frequently observed in the equatorial plasmasphere near harmonics of f_{cH} (*Russel et al*., 1970; *Perraut et al.,* 1982) and harmonics of f_{cHe} (*Kasahara et al.,* 1994).







Magnetosonic waves propagate nearly perpendicular to the background magnetic field and appear very close to the magnetic equator.

MSWs can accelerate radiation belt electrons via Landau resonance (*Horne et al*, 2007).

DE-1 PWI experiment

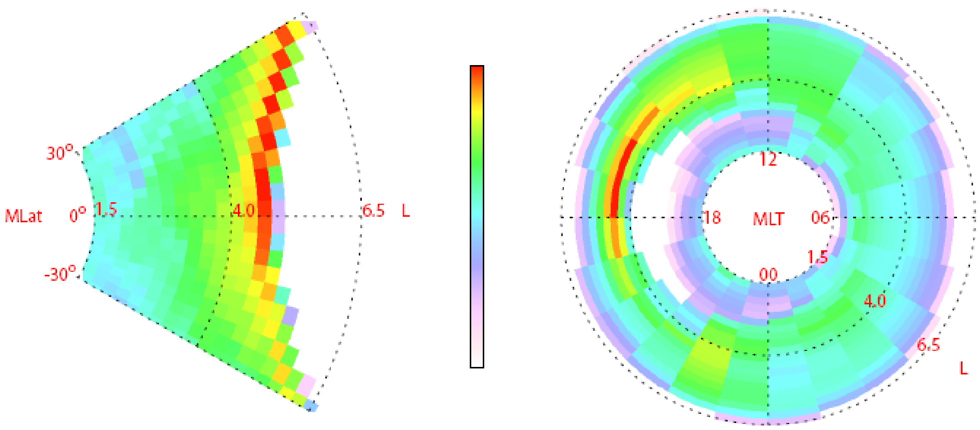
Dynamic Explorer (DE-1) Satellite

- launched in 1981;
- highly elliptical orbit (inclination: 90°; apogee: 3.6 R_E; perigee: 570 km);
- the argument of perigee advances at a rate of 108° per year.

DE-1 PWI Experiment

- Sweep Frequency Receiver (SFR) provides spectral densities of B and E;
- 128 logarithmically spaced frequency channels between 100 Hz and 400 kHz;
- available PWI data covers the period from 09/1981 to 06/1984.

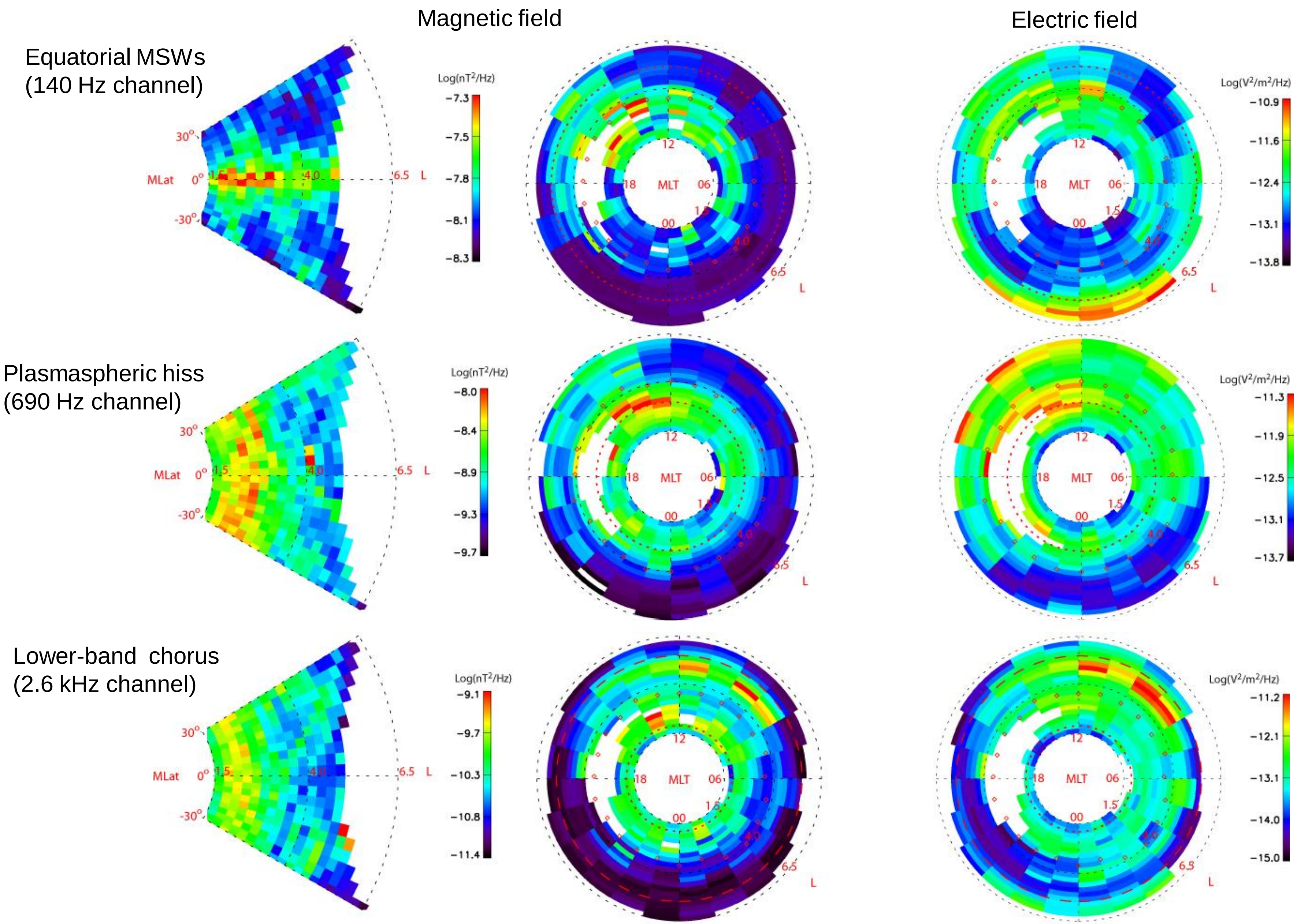
DE-1 Data Coverage: 1.5 < L shell < 6.5 ; -30° < MLat < 30°



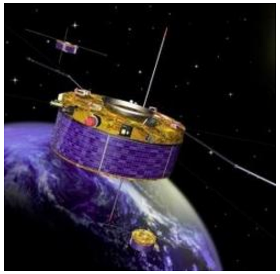
Spatial coverage

- coverage gap in 15-21 MLT sector due to the orbit configuration;
- data from another spacecraft is needed to feel the gap.

DE-1 PWI database

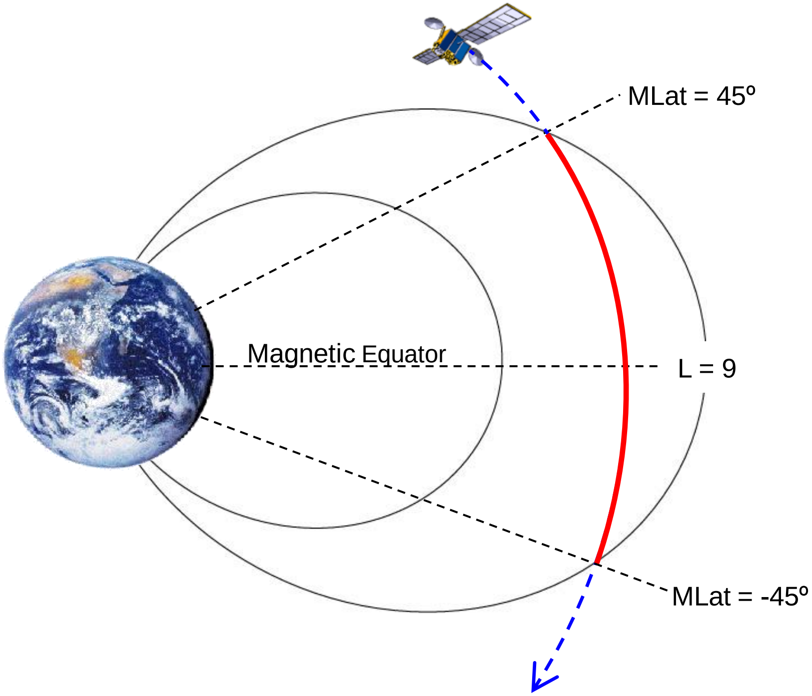


Cluster STAFF-SA Experiment



Cluster STAFF-SA Experiment

- On-board spectrum analyzer provides spectral densities of B_{xyz} and E_{xy};
- 27 logarithmically spaced frequency channels between 9 Hz and 3.6 kHz;
- database includes C-1 data for the period 2001-2004.



Dataset has been restricted in L and MLat:

4 < L shell < 9

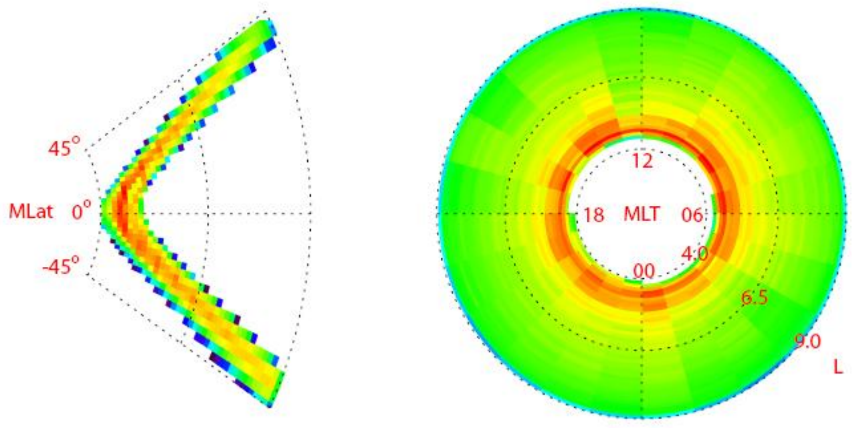
-45° < MLat < 45°

Database dimensions:

L × MLat × MLT
40 × 36 × 24

Cluster STAFF-SA experiment

Spatial coverage of 4 year dataset



Normalized frequency bands

Frequency range	Wave mode
0. 5 $< f/f_{ce} <$ 0.02	MSWs
$f_{lh} < f/f_{ce} < 0.1\ f_{ce}$	Plasmaspheric hiss
$0.1\ f_{ce} < f < 0.5\ f_{ce}$	Lower-band chorus
$0.5\ f_{ce} < f < f_{ce}$	Upper-band chorus

Advantages:

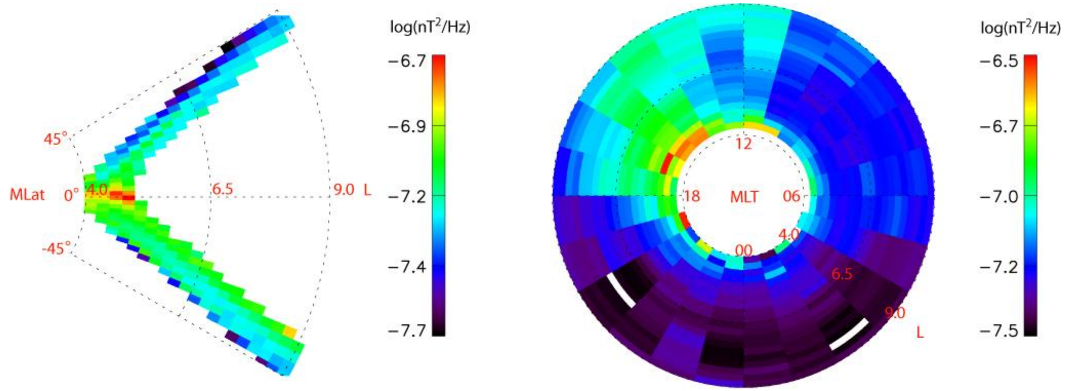
- uniform coverage in MLT;
- covers the regions near equatorial plasmapause important for chorus, MSWs.

Disadvantages:

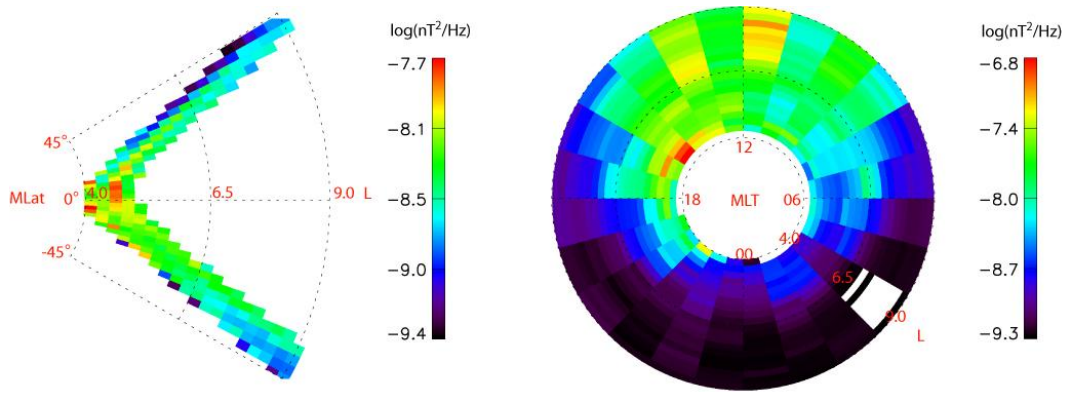
- covers narrow range of L shells at given MLat;
- upper frequency limit is too low (unable to sense upper-hybrid resonance, etc.).

Cluster STAFF-SA Database

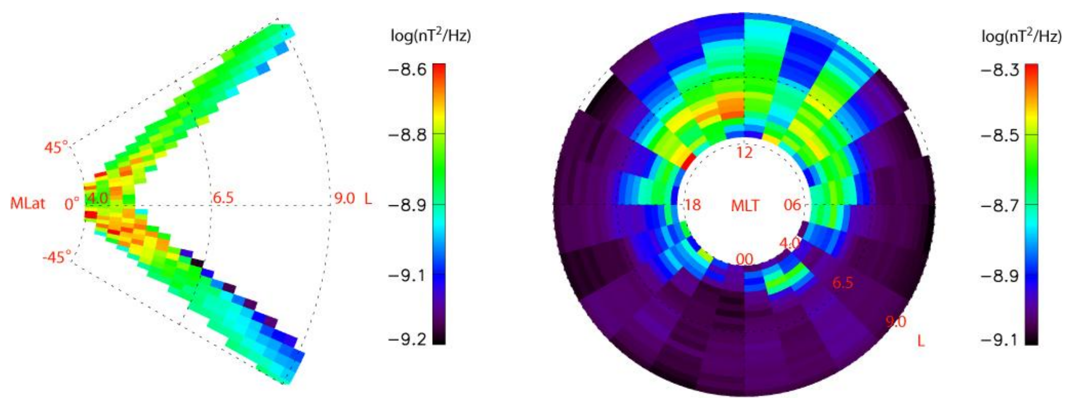
Magnetosonic waves
$f_{cH} < f < f_{lh}$



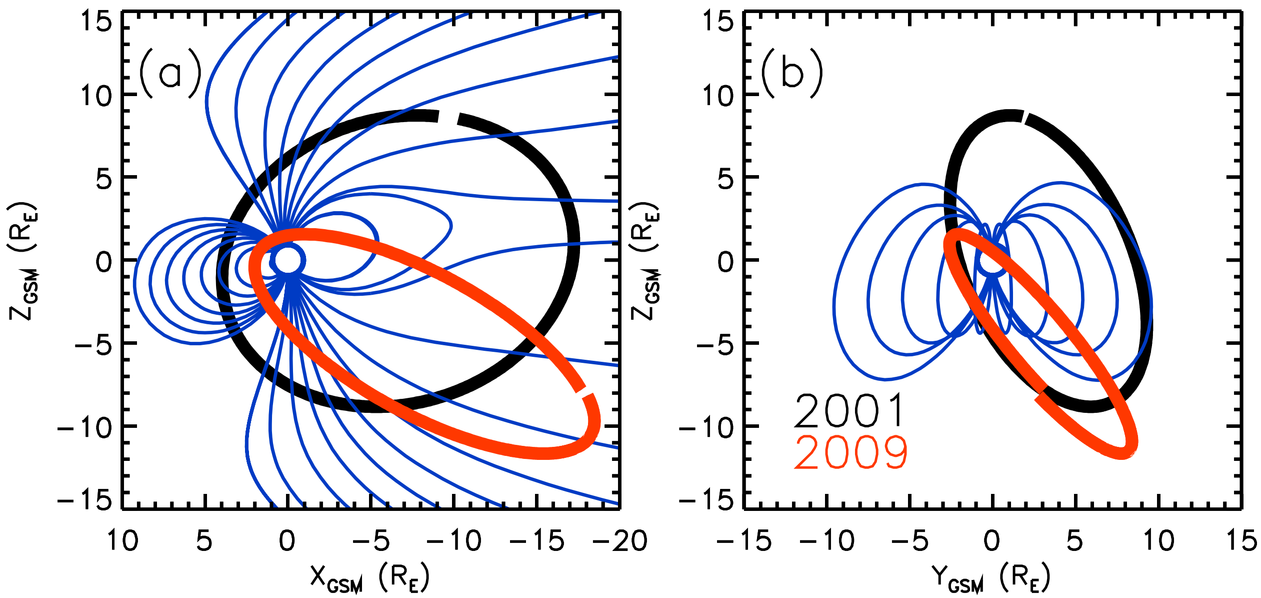
Plasmaspheric hiss
$f_{lh} < f < 0.1\ f_{ce}$



Lower-band chorus
$0.1\ f_{ce} < f < 0.5\ f_{ce}$



Cluster observations near GEO orbit



Courtesy of C. Forsyth, MSSL

Gradual evolution of Cluster's orbits allow the passes near geostationary orbit (starting from late 2008).

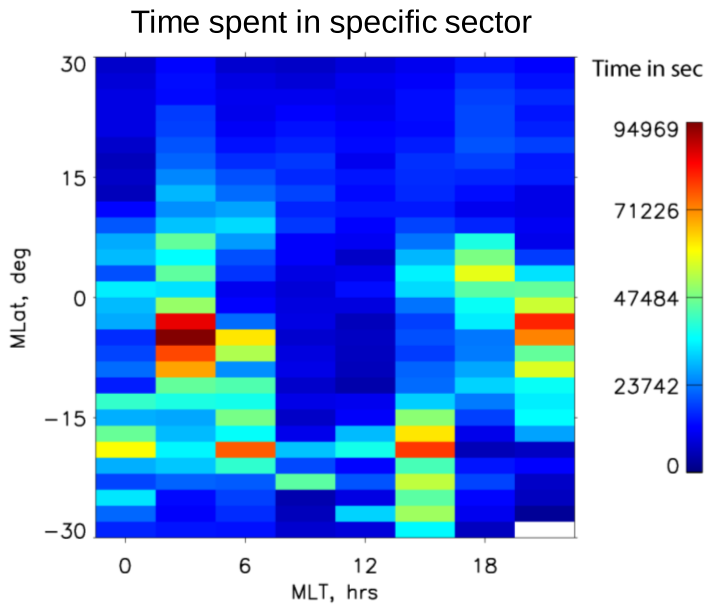
The goal is to link Cluster VLF observations to the electron pressure anisotropies observed by geostationary spacecraft.

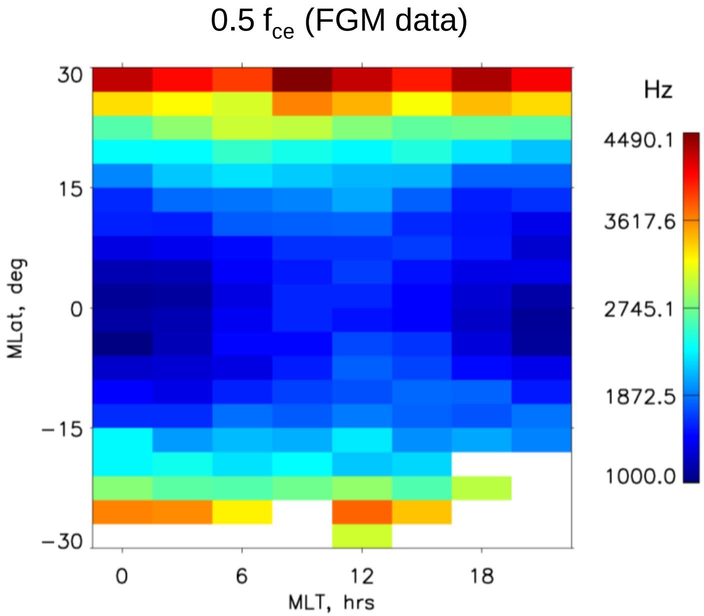
Cluster observations near GEO orbit

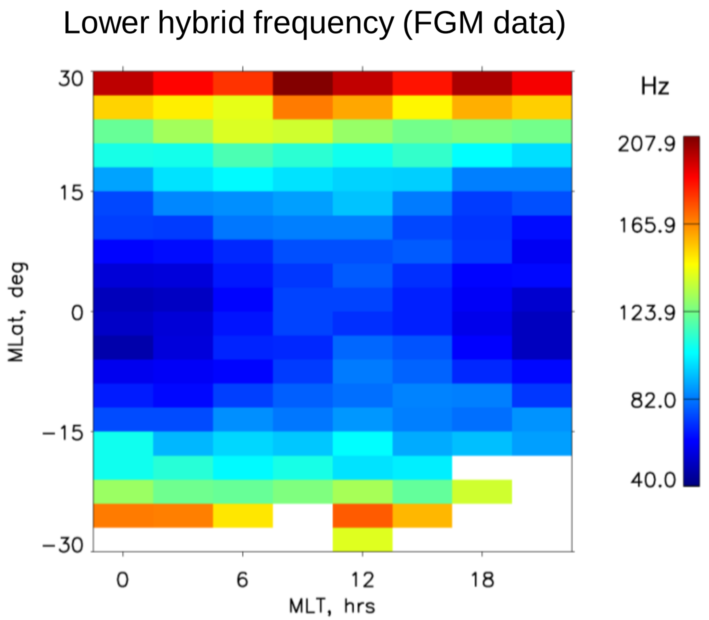
Changes in Cluster orbit allow to analyse distributions of chorus along specific L shells projecting to GEO orbit.

Frequency range is chosen to cover upper/lower chorus bands and to discriminate equatorial MSWs.

Database is limited to L = 6 ÷ 7.2, GMlat = ±30 deg

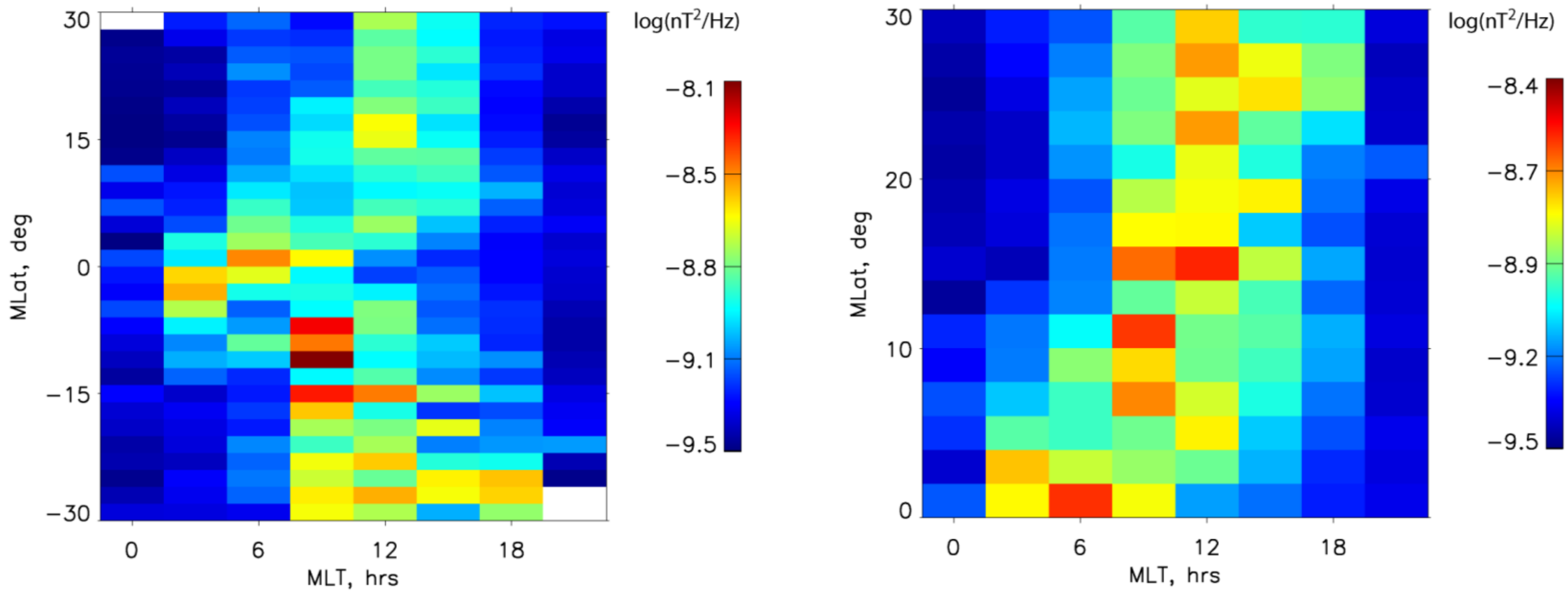


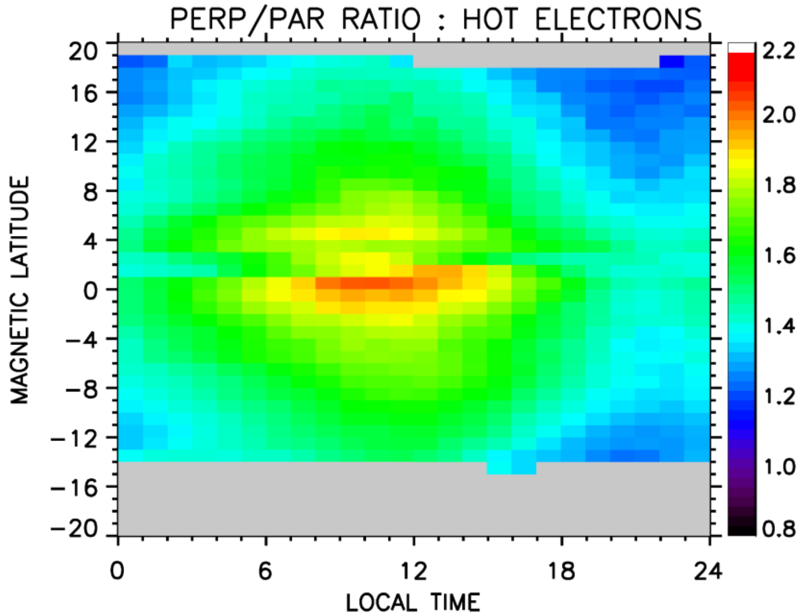




Chorus intensities near GEO orbit

Chorus intensity from STAFF-SA data (2008 - 2012)





Temperature anisotropies of 1 - 40 keV electrons observed by LANL geostationary spacecraft .

The distribution of chorus intensity resembles the statistical distribution of electron temperature anisotropies with chorus maximising in the regions of marginal stability.

Summary

Multi-spacecraft (Cluster, DE-1) statistical database of ELF-VLF wave activity in the outer radiation belts is presented.

The database illustrates MLT - MLat - L distributions of the spectral intensities of chorus, equatorial magnetosonic waves, plasmaspheric hiss, etc. as a function of geomagnetic activity.

The extension of database to recent Cluster orbits (2008-2012) allows us to analyse the distribution of chorus power along a specific L shell at the geostationary orbit.

The results are compared to statistical database of ~ 40 keV electron temperature anisotropies observed by LANL geostationary spacecraft. Preliminary comparison suggests that the chorus intensities are maximising further away from the magnetic equator as we move dawn-ward, i.e. in the regions of marginal stability for the cyclotron instability.

Further Cluster STAFF-SA data (2013-2014) is needed as well as numerical simulations of the chorus generation dynamics.