Multipoint Observations of the Source Region of Whistler-mode Chorus events

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1. Substructure of chorus wave packets

2. Position and size of the chorus source region
   • Central position of the source region from multipoint measurement of the Poynting flux
   • Size of the source region along the field line from multipoint measurement of wave propagation
   • Size of the source region perpendicular to the field line from correlation analysis of chorus elements
   • Average source position: Accumulated observations from Cluster and Double Star 2001-2005

3. Wave-particle interactions in the source region

4. Propagation of chorus from its source
1. Substructure of chorus wave packets
Whistler-mode chorus on 31 March 2001

Power spectrogram of magnetic field fluctuations.

Parallel component of the Poynting vector normalized by its standard deviation.

Angle deviation of the wave vector from the static magnetic field.

Electromagnetic planarity.

Kp: 9-
Dst: -358 nT
AE: ~1200 nT
PLASMA DENSITY ~2/cc
Detailed spectrograms

SEPARATION:

~300 km perp $B_0$

~800 km along $B_0$

$f = 1 - 4$ kHz

$df/dt = 19$ kHz/s

elements of chorus are UNCORRELATED on different spacecraft
Analysis of chorus wave packets

- FIR filter 2-4 kHz
- Envelope of the signal
- Local maxima of subpackets
Amplitudes and delays of the local maxima

Fine structure  Separate wave packets
2. Position and size of the chorus source region
Multipoint measurements: central position of the source

Parallel component of the Poynting vector normalized by its standard deviation.

$Z_{SM}$ coordinate (perpendicular to the geomagnetic equatorial plane) of the four spacecraft.

Typical speed of motion: 100 km/s.
Parallel dimension of the source region

Regions of large values of the electromagnetic planarity

$Z_{SM}$ coordinate (perpendicular to the geomagnetic equatorial plane) of the four spacecraft.

Parallel dimension: ~4000 km
18th April 2002  Cluster 4

Power spectrogram of the electric field fluctuations.

Power spectrogram of the magnetic field fluctuations.

Parallel component of the Poynting vector normalized by its standard deviation.

Angle deviation of the wave vector from the static magnetic field.

Electromagnetic planarity.

Kp: 7°
Dst: -126 nT
AE: ~1100 nT
PLASMA DENSITY~2/cc
Detailed spectrograms 18th April 2002

Cluster 1

Cluster 2

Cluster 3

Cluster 4

CORRELATION COEFFICIENT of elements of the chorus emissions

<table>
<thead>
<tr>
<th>S/C</th>
<th>(D_{\parallel})</th>
<th>(D_{\perp})</th>
<th>(r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–2</td>
<td>120 km</td>
<td>8 km</td>
<td>0.88</td>
</tr>
<tr>
<td>1–3</td>
<td>258 km</td>
<td>72 km</td>
<td>0.28</td>
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<tr>
<td>1–4</td>
<td>200 km</td>
<td>50 km</td>
<td>0.61</td>
</tr>
<tr>
<td>2–3</td>
<td>70 km</td>
<td>69 km</td>
<td>0.30</td>
</tr>
<tr>
<td>2–4</td>
<td>77 km</td>
<td>43 km</td>
<td>0.69</td>
</tr>
<tr>
<td>3–4</td>
<td>-148 km</td>
<td>58 km</td>
<td>0.45</td>
</tr>
</tbody>
</table>
Average latitude-frequency spectrograms
Accumulated STAFF-SA observations 2001-2004

Source of chorus is located within a few degrees of the magnetic equator

Parallel component of the Poynting vector normalized by its standard deviation.

Average of data recorded along the 2001-2004 Cluster orbits close to the perigee

Standard deviation of data recorded along the Cluster orbits close to the perigee
Power-spectral density spectrogram of magnetic field fluctuations measured by Double Star TC-1

Orbits of the TC1 spacecraft during the selected chorus events (thick blue lines). The polar plot represents the McIlwain’s $L$ parameter and the magnetic local time ($MLT$).
Spectrogram of average power spectral density as a function of the McIlwain’s $L$ parameter and the wave frequency $f$ normalized by the equatorial $f_{ce0}$.
3. Wave-particle interactions in the source region
Power spectrogram of the electric field fluctuations. (WBD)

Power spectrogram of the magnetic field fluctuations. (STAFF-SA)

Parallel component of the Poynting vector normalized by its standard deviation. (STAFF-SA)

Angle deviation of the wave vector from the static magnetic field. (STAFF-SA)

Electromagnetic planarity. (STAFF-SA)

Kp: 4 (9)  
Dst: -68 nT (-320 nT)  
AE: ~500 nT

PLASMA DENSITY ~10/cc
PLASMA DENSITY ~ 10/cc

SOURCE OF CHORUS
SOURCE OF CHORUS

PEACE instrument:
electron energy spectrograms
RAPID-Cluster
10/31/2003
21:30--23:30

SOURCE OF CHORUS
Power spectrogram of the electric field fluctuations. (WBD)

Power spectrogram of the magnetic field fluctuations. (STAFF-SA)

Parallel component of the Poynting vector normalized by its standard deviation. (STAFF-SA)

Angle deviation of the wave vector from the static magnetic field. (STAFF-SA)

Electromagnetic planarity. (STAFF-SA)

**24 July 2003  Cluster 4**

Kp: 2+
Dst: -25 nT
AE: ~200 nT

**PLASMA DENSITY~30/cc**
24 July 2003  Cluster 4

C4 SPIN AVERAGED BACKGROUND CORRECTED

High elmag. planarity

Southward flux

Northward flux

High elmag. planarity

SOURCE
PEACE

electron phase space density below 27 keV

count rates used to estimate standard deviations

FIT of a model phase space density

\[ V_{\text{par}} = 9.1 \times 10^4 \text{ km/s} \]

\[ V_{\text{perp}} = 9.1 \times 10^4 \text{ km/s} \]

5 average
Core 7%

- n = 2.5/cc
- $T_{\parallel} = 15$ eV
- $T_{\perp}/T_{\parallel} = 1.5$

Injected 1.3%

- n = 0.5/cc
- $T_{\parallel} = 30$ eV
- $T_{\perp}/T_{\parallel} = 10$

Radiation belt 2%

- n = 0.8/cc
- $T_{\parallel} = 20$ keV

**SOURCE**
4. Propagation of chorus from its source
½ of the electron cyclotron frequency at the equator
Freja 8 April 1995

6:00 - 8:10 MLT
MLat: 56° - 71°,
Alt: 1000 - 1200 km.

Wave vector directions
800 Hz
REVERSE RAY TRACING,
Freja, 8 April 1995

Meridional plane

MLT=6h

Equatorial plane

MLT=6h
Summary

- The chorus wave packets show an embedded fine structure of **subpackets** at time scales from units of ms to a few tens of ms and with maximum amplitudes of a few tens of mV/m.

- Poynting flux measurements show that the source of chorus is located **within a few degrees of the geomagnetic equator**. Maximum intensity is observed by Double Star at radial distances of 8 Earth radii.

- The central position of the chorus source region fluctuates within a distance of **several thousands of km** along the field line, moving at typical speeds of **hundreds of km/s**.

- The **size of the source region** is also **a few thousands of km along the filed line**. Multipoint correlation analysis of separate chorus elements shows that the correlation coefficients decrease at **scales of 100 km across the field lines**.

- Simultaneous measurements of distribution functions of energetic electrons by the PEACE and RAPID instruments will allow us to analyze the source mechanism of chorus and its possible connection to highly accelerated particles.

- Unducted chorus can propagate down to the ionospheric altitudes.