Statistical Study of Lion Roar Emissions Observed by the *Cluster* Spacecraft

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Abstract

Lion roars are intense narrow-band whistler-mode emissions with typical frequencies about 100 Hz. They are frequently occurring in the Earth's magnetosheath. They are thought to be generated by local electron temperature instabilities. The four CLUSTER spacecraft allow us to study the Earth's magnetospehere and its interaction with the solar wind in three dimensions. We have identified about 5000 time-frequency intervals containing the lion roar emissions during 2001 and 2005 in the data of the Spatio Temporal Analysis Field Fluctuations – Spectral Analyzer (STAFF-SA). We present results of a statistical study of Lion roar's spatial, frequency and wave power distribution. We have found that Lion roars are more often observed on the dawn side than on the dusk side of the magnetosheath. We have investigated the orientation of Poyting vector directions of Lion roars calculated from measured spectral matrices using the Singular Value Decomposition (SVD).

1. Introduction

The term "Lion roar" related to plasma waves has been initially introduced by Smith *et al.* [1]. They identified intense narrowband electromagnetic wave emissions at low frequency of about 100 Hz observed by the OGO-5 spacecraft. In a tradition of Very Low Frequency (VLF) pioneers they played the signal through a loudspeaker and the resulting sound resembled a lion's roar.

Kennel and Petscheck [2] suggested that whistler-mode emissions at a frequency f can be generated by an electron cyclotron resonance when the parallel temperature (T_{par}) is larger than the perpendicular one (T_{perp}): $(T_{par} - T_{perp}) / T_{par} > 1/(f/f_{CE} - 1)$, where f_{CE} denotes the electron cyclotron frequency. This assumption has been confirmed by observations of the ISEE-1 spacecraft by Thorne and Tsurutani [3] who also concluded that Lion roars are triggered when the magnetic pressure becomes comparable with the kinetic pressure. Under these conditions the electron cyclotron resonance instability produces Lion roars. However, [4] frequently observed Lion roars not associated with the decrease of the magnetic field in the data of the Geotail spacecraft. These observations can be explained by a hypothesis that Lion roars propagate to the spacecraft from source regions where abovementioned conditions occur.

2. Instrumentation and Methodology

The main aim of the Cluster project is the study of three-dimensional structure of the Earth's magnetosphere and its environment using four identical spacecraft. The Spatio Temporal Analysis Field Fluctuations – Spectral Analyzer (STAFF-SA) onboard processes the signal from the search-coil magnetometer (three components of the magnetic field) and from two antennas of the EFW instrument (two components of the electric field). The multi-dimensional spectral analysis is performed onboard and complex spectral matrices 5x5 are produced each four seconds in 27 logarithmically separated frequency bands from 8 Hz up to 4 kHz [5].

We have used the Singular Value Decomposition (SVD) for propagation analysis of electromagnetic plasma waves [6]. For magnetic measurements only, SVD allows us to simultaneously retrieve wave vector directions (determined in a single hemisphere) and a polarization state of an incident wave. In a case of analysis of three components of the magnetic field and two components of the electric field (STAFF-SA), we can also estimate the parallel component of the Poyting vector normalized by its standard deviation.

3. Results and Discussion

We have found 2908 and 2216 time-frequency intervals containing lion roars observed by Cluster/STAFF-SA in 2001 (high solar activity) and 2005 (low solar activity), respectively. Figure 1 shows an example from our data set. The top panel shows magnetic field fluctuations (B_{SUM}) and we can identify intense narrowband emission around 100 Hz: Lion roars. The ellipticity (L_p) close to one corresponds to the circular right handed polarization and the planarity (F) is roughly above 0.6 for Lion roars.

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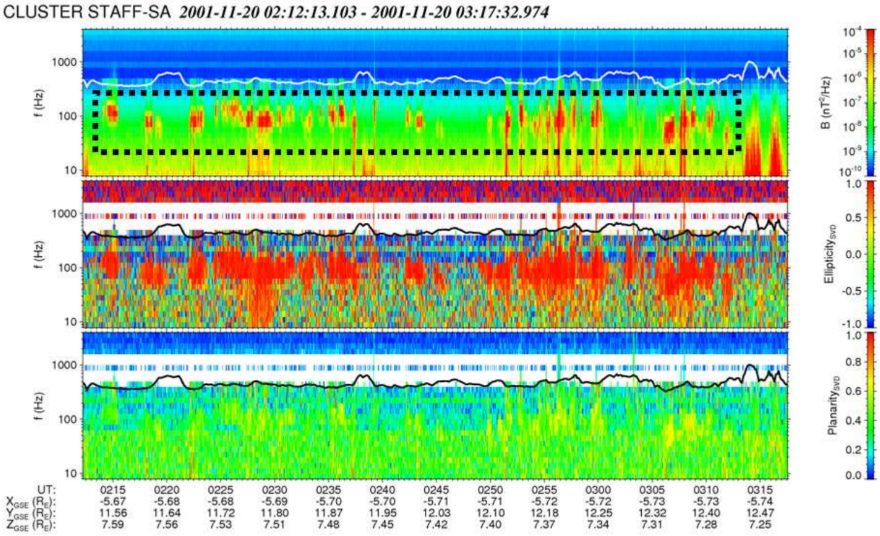

Figure 1. Analysis of measurements recorded from 02:12 to 03:17 UT on 20 November 2001. Top panel: magnetic field fluctuations. Middle panel: the ellipticity calculated by SVD. Bottom panel: planarity calculated by SVD. White/black lines denote f_{CE}.

We have applied following thresholds to remove other emissions and to suppress the background:

- B_{SUM} > 10-7 nT^2/Hz
- $L_p > 0.8$
- $F > 0.6$

We have obtained 578,752 and 574,470 spectral matrices in 2001 and 2005, respectively. We have summarized obtained average values of frequency and wave power distributions in the Table 1.

Table 1. Statistical properties of Lion roars

	2001	2005
$\langle f$ [Hz]$\rangle$	107	114
$\langle f/f_{CE}\rangle$	0.18	0.18
$\langle B_{SUM}$ [nT^2/Hz]$\rangle$	1.80×10^{-4}	9.12×10^{-5}
$\langle E_{SUM}$ [mV^2/m^2/Hz]$\rangle$	7.69×10^{-4}	5.94×10^{-4}

The mean frequency [$\langle f\rangle$] and the normalized frequency [$\langle f/f_{CE}\rangle$] are in a good agreement with [4, 7 – 9]. The magnetic and electric field fluctuations are also comparable with previous studies [9]. Next, we have investigated spatial distribution of Lion roars in the magnetosheath. Figure 2 and 3 shows occurrence histograms of Lion roars in the X and Y components in Geocentric Solar Ecliptic (GSE) coordinates, respectively. X_{GSE} points to the Sun, Z_{GSE} is perpendicular to the ecliptic plane (positive towards the north), and Y_{GSE} completes a right-handed orthogonal set. R_E denotes the Earth's radius. These histograms have been normalized on the spacecraft trajectory. We conclude that Lion roars occur more often in the subsolar region as it can be expected due to a larger temperature anisotropy in this region (Figure 2).

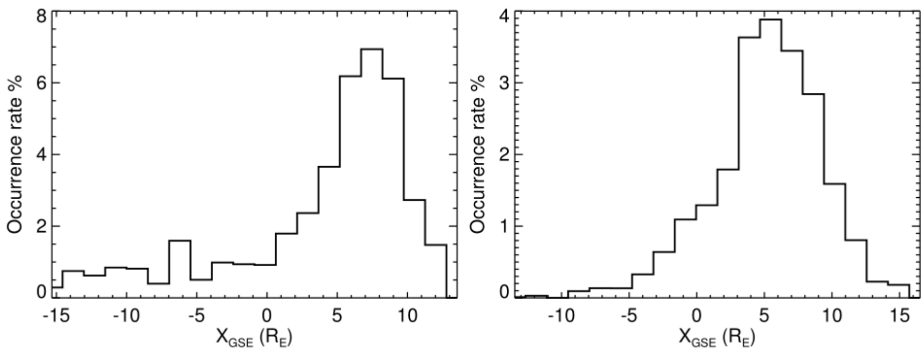

Figure 2. Normalized histograms of Lion roars in X_{GSE} from 2001 (left) and 2005 (right).

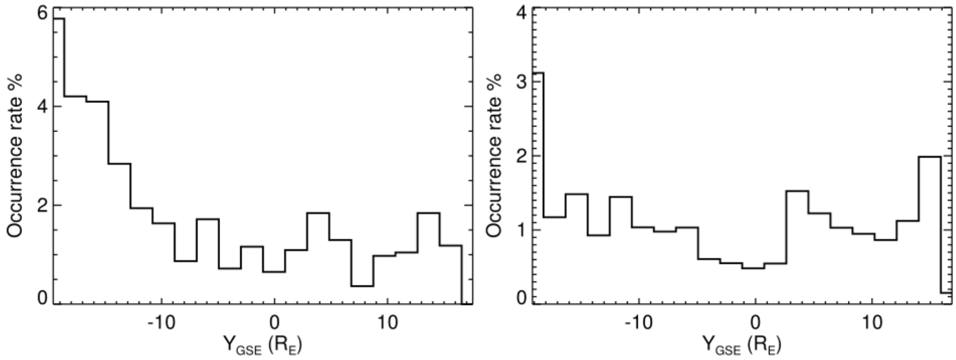

Figure 3. Normalized histograms of Lion roars in Y_{GSE} from 2001 (left) and 2005 (right).

Figure 3 indicates that Lion roars occur more frequently on the dawn side of the magnetosheath (negative Y_{GSE}). This trend is more apparent in 2001 than in 2005. Since the normalized spatial distribution of Z_{GSE} is rather symmetric, we do not show the corresponding histogram.

Generally, Lion roars propagate along magnetic field lines. We have thus used SVD for estimation of the field-aligned component of the Poyting flux normalized by its standard deviation [6]. It reveals us whether an emission propagates parallel or antiparallel to the magnetic field. We have compared this component with the local magnetic field in order to predict the source region. Figure 4 shows the radial component of Poyting vector normalized by its standard deviation in GSE, *i.e.* negative values correspond to the earthward propagation. Our result shows that Lion roars are mainly propagating toward the Earth. We thus expect that the source region is located most often close to the bow shock on the dawn side.

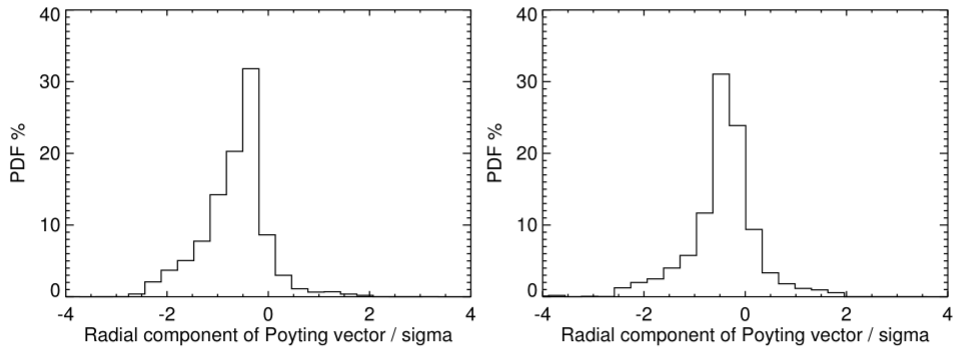

Figure 4. Histograms of the radial component of Poyting vector from 2001 (left) and 2005 (right).

4. Conclusion

In this paper we present statistical results on Lion roars observed by the Cluster spacecraft. We have investigated two years of STAFF - SA measurements (2001 - high solar activity and 2005 – low solar activity). We have found a total of 5124 time-frequency intervals. We have applied thresholds on intensity, ellipticity, and planarity magnetic field fluctuations to remove other emissions. Finally, we received a total of 1,153,222 spectral matrices for further analysis.

Our main results on Lion roars are as follows:

- Lion roars are observed throughout the magnetosphere with a predominance on the dawn side of the subsolar region.
- The mean frequency and normalized frequency correspond to previous studies [4, 7 – 9].
- Our results show that the Lion roars generally propagate towards the Earth.
- We have found no noticeable differences between the data from periods of higher (2001) and lower (2005) solar activity.

The results give a good basis for further exploration of the properties of lion roars. We plan to compare the observed electromagnetic emissions with other plasma parameters (*e.g.*, density, temperature anisotropy, etc.)

5. Acknowledgments

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6. References

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