2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

Properties of quasi-periodical VLF emissions from ground-space conjunctions and multi-point observations.

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Abstract

We report characteristics of VLF quasi-periodical (QP) emissions using multi-point observations on the ground and in space, as well as ground-space conjugate events. We present information on the size and extension of the equatorial source region for QP emissions. We present two rare conjugate events in which the ground station of Kannuslehto observes the same QP as the ERG (Arase) satellite. These events were observed during two distinct geomagnetic conditions and at almost opposite magnetic timings. This is the first time we can use such events, observed by the same instruments at two different timings, to compare the generation, propagation properties and physical characteristics of QP emissions. Combined with observations by other spacecraft and ground stations, these events also offer a unique opportunity to elucidate the mechanisms behind the periodicity of the emissions, as well as information on their source.

1. Introduction

Extremely Low (ELF) and Very Low Frequency (VLF) emissions are naturally occurring magnetospheric plasma waves (3 Hz < f < 30 kHz) propagating in the whistler-mode. Through wave-particle interactions they accelerate or scatter electrons playing an important role in radiation belt dynamics [1, 2, 3, 4]. Among these types of waves, chorus emissions are one of the most famous, however there are several other types [5]. One of them is known as quasi-periodic (QP) emissions, due to the fairly regular periodic modulation of their wave intensity. Although there are several speculations, the origin and principal mechanism behind this modulation is so far still unclear [6,7,8,9].

One of the objectives of this study is to use multi-point observations on the ground and in space to gather more information on the properties of QP, in particular to elucidate the mechanisms behind their regular periodicity. Combining ground-based observations using subauroral stations, we have gathered information on the longitudinal propagation of QP and eventual differences between night time and day time emissions. Conjugate events, in which we observe the same waves on the satellite and on ground have helped us to understand the propagation properties of the waves. To our knowledge, these events are rare and far in between, with currently only two cases of conjugate QP emissions between ground and space [10, 11]. This study presents two additional singular conjugate events bringing unique information on QP properties. We have estimated the size and characteristics of the active wave source. We also investigate the link between QP and chorus and the role played by density in the spectral features of these waves. We can compare, for the first time, two conjugate events between the same ground-station and satellite, happening during different geomagnetic conditions (quiet vs. active) and on almost opposite sides of the magnetosphere (morning vs. midnight side).

2. Instruments

To monitor waves on the ground, we use VLF receivers from the PWING project [12] located at subauroral latitudes in Athabasca [ATH, MLAT=61.2N, L=4.3] and Kapuskasing [KAP, MLAT=58.7N, L=3.7], Canada. These stations are also equipped with magnetometers, all-sky cameras and riometers. Conjugate observations were made using the VLF receiver from the Soddankyla Geophyical Observatory in Kannuslehto [MLAT=64.4N, L=5.3], Finland. Details on the receivers for ATH and KAP can be found in [13] and [14], and [15] for KAN.
Observations in space were made by the Van Allen Probes (RBSP-A and -B) and the ERG (Arase) spacecraft. Electric and magnetic field data for RBSP was provided by the Electric Fields and Waves Instruments providing [16] and for ERG by the Plasma Wave Experiment [17].

3. Conjugate Event 1

We report a QP conjugate event between KAN and ERG on March 28, 2017 from ~22:36 to 23:00 UT, a few days after strong geomagnetic activity. A 10-min snapshot of the event is shown in **Figure 1**. The event was observed during the recovery phase of a storm, in a period of sustained high solar-wind speed and with 400 < AE < 800 nT. The conjugate event happened in the post-midnight sector (00 – 02 MLT). We checked for geomagnetic pulsations using the induction coil magnetometer at Sodankyla (SOD), 35 km from KAN. No geomagnetic pulsations were observed at the time of the event, however some Pc1 activity is observed between 21 – 22 UT. No pulsations were observed on board ERG.

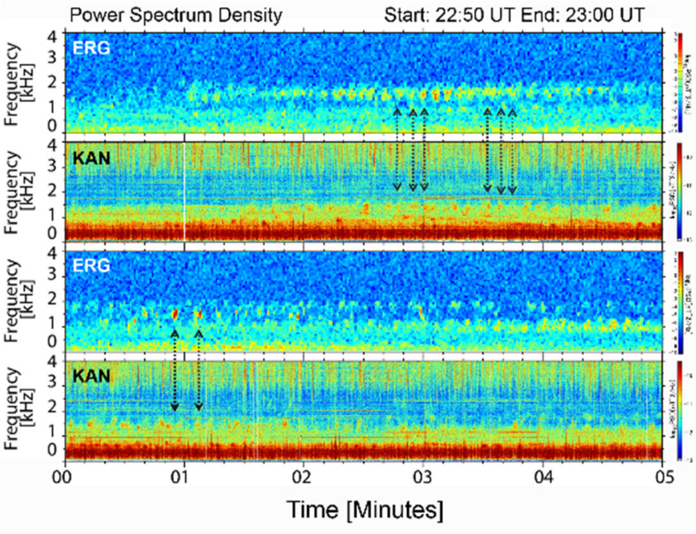

Figure 1. PSD at ERG and KAN showing a 10-min snapshot of the conjugate event from 22:50 to 23:00UT and frequencies between 0 and 4 kHz. The name of the observation point is indicated on the top left corner. Black arrows indicate examples of corresponding QP elements in both locations.

3.1. Multi-point observations

On March 28 and 29, 2017 several QP emissions were observed on KAN, ATH and KAP. They usually were observed while the stations stayed on the dayside (06 -13 MLT), except for KAN where they were observed from 00 – 20 MLT. During these two days, both RBSPs were mainly on the dusk side. RBSP-B moving ahead of RBSP-A by only ~1-2 MLT difference. RBSP-B observed both chorus and QP, while RPBS-A close behind, saw only chorus. This suggests that for this particular disturbed conditions, the active source for QP is smaller than that of chorus, and should be < 2 MLT.

At the time of the conjugate event between KAN and ERG, RBSP-A (east of KAN) does not observe QP but a hiss-like emission with periodic bursts. ATH observed QP with different periodicity and frequency but they stop several minutes after the QP starts at KAN. This suggests that in this case, the periodicity observed in different locations might be the cause of an external global factor, possibly related to the compression and/or oscillation of the magnetosphere during geomagnetic active times.

3.2. Ground-Space conjunction

The QP on the ground has low right hand polarization which can be explained by the ionospheric exit point being located just above or near KAN. As show in Figure 1, observations on both locations (ERG and KAN) show the same spectral and frequency features, as well as changes in frequency not shown here for brevity. One-to-one correspondence of QP elements is not always visible, probably due to overlapping emissions on the ground. Usually because several waves can exit the ionosphere close to the ground-station, VLF emissions on the ground are easily mixed. However, in this example we can see correspondence of some QP elements, examples of which are indicated by black arrows on Figure 1. After ~23 UT, however, we are not able to confirm that KAN and ERG are observing the same. We can however speculate that some of the waves observed on the ground might be coming from the same active source. Using these timings and the magnetospheric footprint of the satellite calculated by Tsyganenko model TS04 [20], we extrapolated the size of the source at the equator. We found that the active QP source is less than 6200 km at L~5.

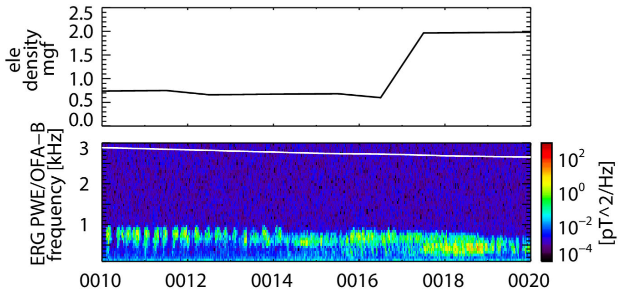

Figure 2. Top: Electron density obtained from the upper hybrid frequency and magnetic field measured by the MGF instrument of ERG. Bottom: PSD of the magnetic field from 0 to 3 kHz. Pink line indicates calculated electron half-gyrofrequency. Horizontal axis indicates time in UT.

At around 00 UT, ERG observes a very clear QP emission that later transforms into chorus, as shown in **Figure 2**. At the time of the spectral changes, we observe a clear increase on the electron density. In a one-hour time frame, this is also observed in two other occasions. This suggests that QP and chorus emissions could be more related than previously thought and that density might play a significant role in the appearance of periodicity in VLF emissions. We suggest that ERG is going through an active VLF source that includes regions of higher or lower density, these regions then become active sources for chorus or QP, respectively. Another suggestion would be that the whole region is actively generating chorus and the density changes would help modulate the spectral features into QP.

4. Conjugate Event 2

We also report another QP conjugate event between KAN and ERG on November 30, 2017 from ~09:30 to 10:20 UT. This time the event happened during a geomagnetic quiet time and on the day side (11 to 13 MLT). Dst was between 0 and -10 nT and AE < 100 nT. The event is shown in its entirety in **Figure 3**. One-to-one correspondence of QP elements can be clearly seen during almost the whole event (in particular at 10:00 UT). The event continues to be observed on the electric field data for at least 15 more minutes (not pictured). The study of the ratio of intensity between Electric and Magnetic field components using cold plasma distribution will give us information on the wave normal angle of the waves. We also use spectral matrix data from ERG to obtain polarization parameters and estimate wave normal angles. The drop in magnetic field intensity at ~10:10 UT corresponds to a clear drop on the upper hybrid frequency (not pictured). No associated geomagnetic pulsations were observed at this time at ERG. SOD shows a Pc1 event starting at ~11 UT which would be ~30 minutes after the end of the emission at ERG.

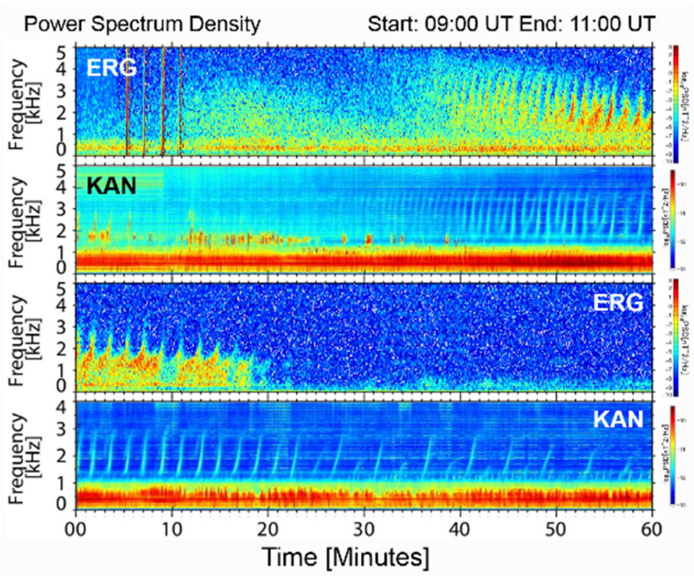

Figure 3. PSD at ERG and KAN showing the entire QP conjugate event. The time frame covers 2 hours from 09:00 to 11:00 UT and frequencies from 0 to 5 kHz. Observation points are indicated on top of each panel. One-to-one correspondence of the QP elements is evident, in particular at 10:00 to 10:10 UT.

4.1. Multi-point observations

Unlike the previous conjugate event, this one is observed at a geomagnetic quiet time. No other QP emissions were observed in the 24 hours preceding the conjugate event on any of the 4 VLF working receivers of the PWING project (ATH, GAK, KAP, MAM). Besides the occasional hiss, some chorus was observed by Maimaga station (MAM, MLAT=58.0, L=3.56) at 22 UT. At the time of the event, both RBSPs were located ~ 2 to 3 MLT behind ERG however ~ 3 R_E outwards. While ERG was approximately at an MLAT = 26 degrees, both RBSPs were located ~10-15 degrees northwards of the geomagnetic equator. Neither RBSP-A or -B observe QP at this time, however both spacecraft observe chorus emissions. RBSP-A from 06 to 10 UT and RBSP-B from 10 to 11:30 UT. This correlates with previous results suggesting that the active QP source is < 1 -2 MLT and smaller than the chorus source. The radial (longitudinal) extent of the source would be < 3 R_E in correlation with previous calculations of 6200 km.

4.2. Ground-Space conjunction

The QP event at KAN lasts from ~09:30 to 12:30 UT, while the conjugate observation between KAN-ERG only covers the first hour of this time interval. At this time the periodicity changes observed did not correspond to any changes in density. While the RBSPs spacecraft, closer to the equator, and KAN observe chorus (09:00 to 09:40 UT in Figure 3), ERG only sees QP and hiss. No great density variations are observed in either case that could suggest a relationship between density changes and spectral features. Since no other QP emissions were observed at other ground-stations we can suggest that the mechanism behind this effect is probably spatially localized. As the other satellites observe chorus emissions at similar timings, we can however suggest that the QP generation might be linked to the chorus emissions observed by RBSP closer to the geomagnetic equator. This would mean that the periodicity could be related to propagation or a mechanism outside of the source. However, we cannot rule out that the QP is simply generated at a different source than the chorus and its periodicity would be related to the source characteristics.

This event shows incredible one-to-one correspondence between the QP elements observed on the ground and those in space. This makes it a perfect candidate for both a correlation analysis and ray tracing, allowing us to improve our understanding of wave propagation to the ground. We can also gather information of the conditions that allow for this event to easily propagate to the ground, compared to the event observed during more active geomagnetic times.

We will also include in this study, ERG particle data to discuss related electron flux modulations, especially for the pitch angle distributions for both events. Additionally, we can also use these events to identify the global (latitudinal) source size of QP emissions using ERG-PWE data, while coherence between ERG and the ground can give us the local source size. Finally, a comparison between these conjugate events can give us additional information on how external geomagnetic conditions affect wave generation and propagation to the ground.

5. Summary

We present two separate conjugate events in which the same QP emissions are simultaneously observed by the ground station of KAN and the ERG satellite. These events are complemented by observations made from subauroral ground stations from the PWING network and both RBSP probes. Using the data from multiple locations we have discussed the extent of the QP active source and the possible relationship between QP and chorus generation. We found that the active QP source should not extent more than 2 MLT and 3 R_E radially. We also discuss possible origins for the periodicity of the observed QP emissions. In case 1, during active times, it could be related to a global magnetospheric mechanism or related to chorus emissions and density changes. On the other hand, during quiet times, as is case 2, the periodicity might be linked to the source characteristics or due to a mechanism encountered during propagation. Additional study of electron flux variations, pitch angle distributions and wave analysis will allow us to have a better understanding on these events as a whole.

6. Acknowledgements

ELF/VLF data is available at http://stdb2.stelab.nagoya-u.ac.jp/vlf/index2.html for PWING stations and at http://www.sgo.fi/pub_vlf/ for KAN. We thank Y. Katoh, H. Hamaguchi, Y. Yamamoto and T. Adachi of ISEE, as well as K. Reiter from Athabasca University, for their continued technical support. EMFISIS data is available at http://emfisis.physics.uiowa.edu/Flight/. ERG data will shortly be publicly available at http://ergsc.isee.nagoya-u.ac.jp. Solar wind parameters were obtained from SPDF/GSFC OMNIWeb database and WDC for geomagnetism, Kyoto. This work was supported by Grants-in-Aid for Scientific Research (17F17030) of the Japan Society for the Promotion of Science and by the JSPS International Research Fellowship. The research at University of Iowa was supported by JHU/APL contract 921647 under NASA prime contract NAS5-01072.

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