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A Study of the Large-Scale Dynamics of the Jovian Magnetosphere using the Galileo Plasma Wave Experiment

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Abstract. Using observations of the Galileo PWS experiment, we show that energetic phenomena recurrently occur in the jovian magnetosphere. They are characterized by intensifications of the auroral radio emissions and the creation of new sources of radiations in the outer regions of the Io torus. Simultaneously, modifications of the structure of the plasmasheet are observed at large distance (more than 60 Rj) from Jupiter. These large-scale processes, presenting a periodicity of 50 to 80 hours, could be linked to global instabilities of the jovian magnetosphere.

Introduction

What are the different types of activities in planetary magnetospheres? Answers to this question have been given in the terrestrial case only. It is indeed known that the Earth's magnetospheric activity is mainly associated with geomagnetic substorms. These recurrent processes, related to variations in solar wind (SW) parameters, consist of explosive releases of magnetic energy which strongly heat the magnetospheric plasma. They trigger powerful acceleration processes in the auroral regions and considerably increase the flux of the auroral kilometric radio emissions (AKR).

The possible existence of a similar type of activity in other planetary magnetospheres is still an open question. In a first attempt to answer it, one can use the numerous papers describing observations of possible SW effects on planetary radio emission. The SW has thus undoubtly a strong influence on the generation of the Saturn Kilometric Radiation (SKR) (*Desch*, [1982], *Desch and Rucker*, [1983]). However, since the SKR is generated in the dayside (*Galopeau et al.*, [1995])- a situation very different from the AKR - it seems difficult to relate the SKR to substorm-like phenomena. The SKR is more likely linked to the development of a Kelvin-Helmholtz instability in the morning side of the magnetopause, a type of SW effect that has little in common with the strong control of the magnetospheric dynamics observed in the Earth's case. In contrast, the jovian magnetosphere is characterized by its very strong internal activity. Nevertheless, using Voyager data, *Zarka and Genova* [1983] were able to show the existence of a modulation in jovian emissions at harmonics of the solar rotation period. This positive correlation between jovian emissions and fluctuations in the SW was confirmed later on (*Desch and Barrow,* [1984], *Barrow and Desch*, [1989], *Kaiser,* [1993]) and a direct observation of a SW action on the magnetosphere was even reported (*Prangé et al,* [1993]). Despite these observations, the difficulty to detect possible SW effects indicates that the jovian magnetospheric activity is only marginally affected by the SW. Hence, for different reasons, both the jovian and the saturnian cases greatly differ from the terrestrial one.

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Does it mean that substorm-like phenomena are specific to the Earth's magnetosphere? Due to Io's volcanic activity, the inner region of the jovian magnetosphere is subject to a permanent mass loading. The balance between the centrifugal force and the magnetic confinement could lead to out-of-equilibrium states which periodically relax, by a pure internal process or the action of an external perturbation of the SW. Such processes would present some analogies with geomagnetic substorms. In order to examine this issue, we propose here an analysis of the radio and plasma waves measured by the Galileo PWS experiment during the september/october 1996 period (orbit G2).

An example of a long-term survey of the jovian radio emissions by Galileo

In figure 1, a time-frequency spectrogram gives a survey of the PWS observations from day 18/09/96 to day 12/10/96 (during the second orbit of Galileo around Jupiter). These data were recorded as Galileo, located in the ecliptic plane, was moving away from Jupiter (60 Rj to 110 Rj), in the nightside of the magnetosphere. This compressed view of 57,870 spectra recorded every 36.7 s are constituted by 152 frequency channels ranging from 5.6 hz to 5.6 Mhz (see *Gurnett et al.* [1992] for more details). This spectrum illustrates the capability of the PWS instrument (see *Kurth et al.* [1998] for a first overview of the observations) which can simultaneously act as a remote-sensing radiotelescope and also perform local measurements.

Above 500 kHz, the experiment detects emissions of auroral origin. They are related to the auroral activity and present similarities with the AKR. Between 500 kHz and 50 kHz, two types of radiation are observed: a sporadic one

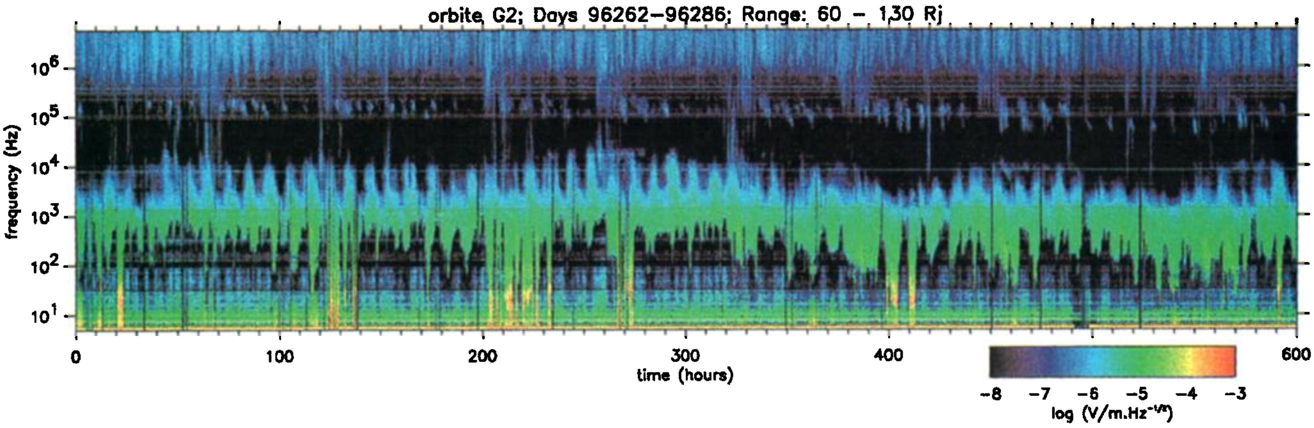

Figure 1. 25 days of PWS observations recorded during the orbit G2

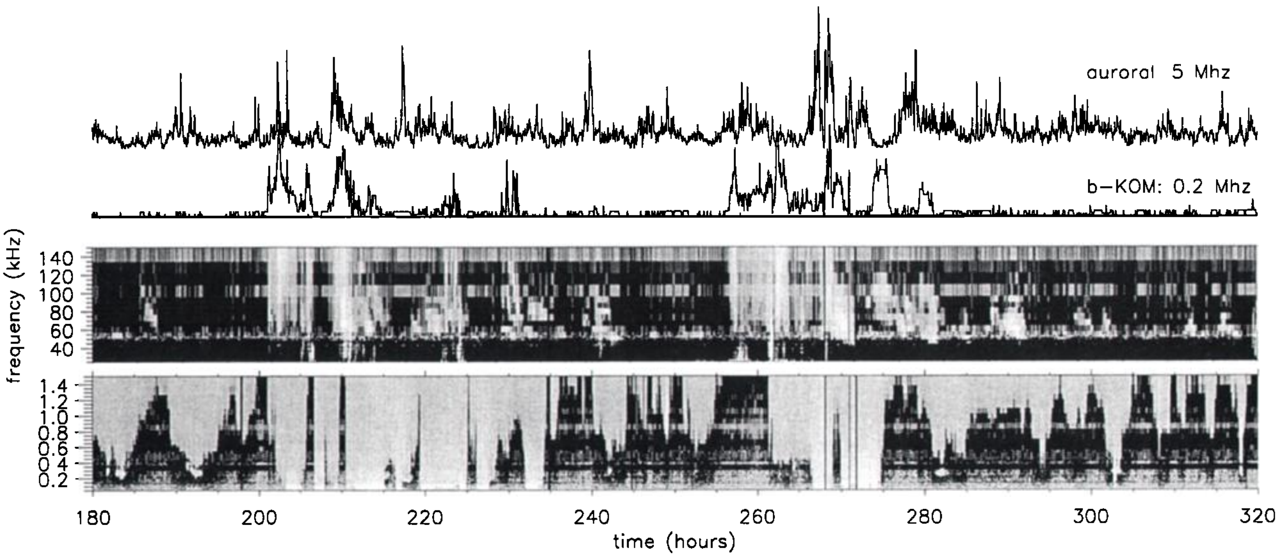

Figure 2. Detailed temporal evolution of events. The flux at 5 and 0.2 Mhz is presented using a linear scale. The maximum intensity is 2 10^{-7} V/m.hz $^{-1/2}$ at 5 Mhz.

observed during 7 or 8 periods of a few hours: the b-KOM (observed at 70:00, 120:00, 190:00...), and a more specific one characterized by a remarkable 10 hour recurrence : the n-KOM. While the b-KOM has an auroral origin (*Ladreiter et al.* [1994]), the n-KOM is emitted by a few distinct sources which corotate in the outermost part of the Io torus (*Reiner et al.* [1993]). Below 10 kHz, one detects the continuum radiation. Its lower frequency cut-off, perfectly visible in figure 1, can be used to determine the local plasma frequency. The analysis of figure 1 can thus give an insight into the activity in different regions of the magnetosphere. The decametric and hectometric radiations

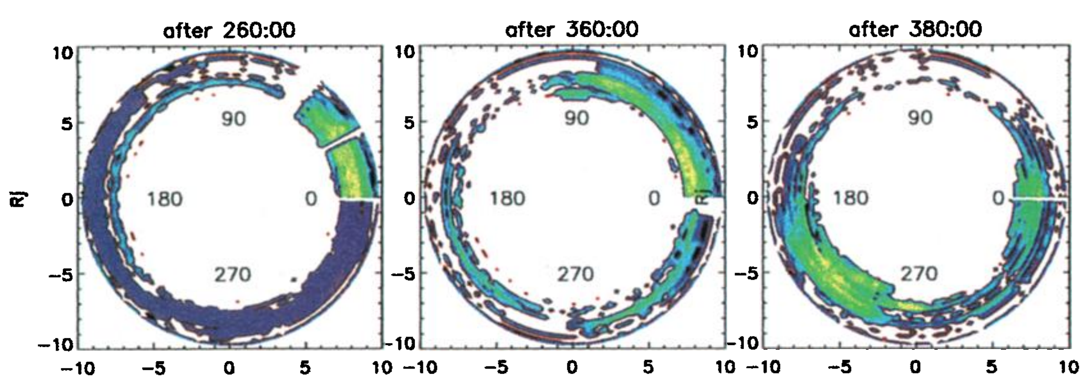

Figure 3. Expected positions of the sources of n-KOM assuming that the radiation is generated in the equatorial plane, at the plasma frequency. The polar angle is the system III longitude.

can be used to survey the energy dissipation in the auroral zones. Modifications in the morphology of the n-KOM indicate that an activity has taken place near the Io torus. Finally, using the cut-off of the continuum radiation, one can detect fluctuations in the configuration of the plasmasheet .

The strong modulations at periods of 5 or 10 hours seen on the spectrogram are directly linked to Jupiter's rotation. On longer time scales (60 to 100 hours), events characterized by intensifications of the auroral radiations and sudden detections of the b-KOM are observed. During the 25 days of observation reported here, approximately 8 events of that type occurred: at 70:00, 120:00, 205:00, 260:00, 330:00, 380:00, 450:00 and 555:00. They are accompagnied by brightenings and modifications in the number or in the spectral signature of individual sources of n-KOM as this, for example, clearly appears after the event at 450:00. Occasionally, in relation with these events, the cut-off frequency of the continuum radiation decreases below 100 hz and its systematic modulation at 5 or 10 hours is no longer apparent.. This quasi-periodic activity which simultaneously affects both the auroral and the n-KOM radiations and associated with plasmasheet perturbations has not been reported before. It clearly corresponds to the existence of a large scale activity of the jovian magnetosphere.

The temporal behaviour of these phenomena is shown more quantitatively in figure 2. Here, we focus on the period 180:00 – 320:00 during which 2 events occurred. Two time series, corresponding to the auroral emission (5 MHz) and to the b-KOM (0.2 MHz), are presented. The b-KOM is not detected except during short periods which precisely correspond to the events. Since Jupiter has a rather continuous activity in the kilometric domain, this means that Galileo is generally not in the beam of this emission. The propagation of this radiation is known to be strongly affected by the Io torus and the magnetodisc *(Ladreiter and Leblanc,* [1990]), so its sudden detections could indicate that the plasma distribution in the magnetodisc is modified during the events. At 5 Mhz, the temporal behaviour is more complex. The auroral emissions are always detected and present fluctuations which can simply be due to local variations in the auroral activity, not necessarily related to more global processes. Nevertheless, the most important fluctuations are clearly associated with the events. They correspond to flux enhancements by factors up to 5 and generally lag somewhat behind the bursts of b-KOM. More precisely, if the time serie is divided into intervals corresponding to one Jovian rotation (approximately 10 hours), one can check that the maximum auroral fluxes are observed during the interval that immediately follows the detections of b-KOM, even if the auroral flux is already reinforced at the times of b-KOM detection. Thus, the mechanism that trigger the b-KOM activity seem to have an immediate counterpart in the auroral domain, but the maximum auroral activity is observed with a delay of a few hours.

In the middle panel of figure 2, the dynamic spectrum in the frequency range 40- 120 kHz is displayed. The emission presenting a 10 hour periodicity is the n-KOM. Clearly, the energetic events mark the beginning of intervals lasting 3 to 5 jovian rotations during which the n-KOM is particularly strong. Its intensity then decays gradually and can even vanish before to be turned on again by a new event. From one event to the next, the number as well as the spectral signature of the individual sources are generally modified. This is described more precisely in figure 3 where polar plots indicate an approximated position of the sources in radial distance and in systeme III longitude. To build these plots, we have considered periods of time corresponding to one rotation of Jupiter just after the events at 260:00, 330:00 and 380:00. Then, assuming that the n-KOM is produced at the plasma frequency, the source/Jupiter distance can be obtained from a model of the torus and, since the n-KOM is emitted radially (*Reiner et al.* [1993]), the longitude of the sources is just the same as the one of Galileo when it detects the n-KOM. Displaying the n-KOM spectrogram in this kind of polar coordinates thus gives the localization of the active regions in the Io torus. The very interesting point shown here is that each event corresponds to the creation of new active regions in the Io torus. For example, three sources are observed following the event at 260:00: a strong source with a large longitudinal extent (between -10° and 45°) and two fainter ones (around 180° and 270°). After the next event , both faint sources have disappeared and only one source remains, extending from -10° to 90°. After 380:00, a bright new source, in a completely different part of the torus, is visible around 230°. Compared to the dramatic modification in the spatial localization of the sources that occurs during events, their evolution between each event is reduced to a gentle intensity decay. Hence, the magnetospheric process that triggers bursts of b-KOM and intensifies the auroral radio emissions has a sufficient impact on the outer regions of the Io torus to completely reorganize the sources of n-KOM there.

In the lowermost panel of figure 2, the low-frequency part of the spectrogram (50 Hz to 1.5 kHz) is presented to show the cut-off of the continuum which is at or very near the plasma frequency. This cut-off hardly reaches 2 kHz (density of 0.05 cm^{-3}) and can be as low as 200 Hz (density less than 0.001 cm^{-3}). These two extrema correspond to crossings of the dense regions of the plasmasheet and to incursions into the lobes. Shortly after the events, the cut-off drops to extremely low frequencies (less than 100 Hz) and its 5 or 10 hour oscillations are sometimes no longer visible. A comparison with the magnetometer data shows that during these periods of extremely low values of the cut-off, Galileo has entered regions where the plasma frequency is lower than the electron gyrofrequency (lower than 100 Hz), which could be compatible with the density in the lobe regions. Another interesting observation is that the crossings of these very low-density regions sometimes occur with a 10 hour periodicity. As seen in figure 2, a short lasting crossing (one hour duration) is observed with a 10 hour recurrence (at 207:00, 217:00, and 227:00) and a longer crossing (from 210:00 to 215:00) is again observed almost 10 hours later (219:00 to 225:00). A possible explanation of this periodicity would be that the plasmasheet presents kinds of longitudinal disruptions which could be linked either to the existence of extremely low-density regions, to sudden shifts in latitude of the central part of the plasmasheet or to plasmasheet thinnings limited in latitude. Nevertheless, whatever the nature of these low-density regions, their systematic crossings after the events illustrate the very large spatial scale of the magnetospheric perturbations reported here.

Conclusion

The PWS Galileo experiment detects large-scale magnetospheric phenomena which recurrently affect the auroral activity and modify the characteristics of the active regions in the outer Io torus. They are followed by important modifications in the configuration of the plasmasheet. The onset of these events coincides with the sudden detection of b-KOM, an emission which is normally not observed by Galileo during the orbit G2, and the observation of an inceased power in the higher frequency auroral radio emissions. Correlatively, the n-KOM sources are renewed and the associated radiation flux intensifies. With a few hour delay with respect to the first b-KOM detection, Galileo (located at more than 60 Rj) crosses, for short periods, regions of extremely low density that could be interpreted as longitudinal disruptions of the plasmasheet.

A comparison with the data from the energetic particle instrument (*Krupp et al., Woch et al.*, submitted to GRL) and from the magnetometer shows that the energetic events reported here also correspond to flows of energetic particles and to strong magnetic perturbations. Coming back to the question raised in the introduction, these observations would show that the jovian magnetosphere is periodically affected by large-scale energetic phenomena which could present some analogies with the terrestrial substorms, since they control the different radio emissions and also correspond to reconfigurations of the plasmasheet. Their exact nature and especially their triggering process remain to be determined.

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