GEOPHYSICAL RESEARCH LETTERS, VOL. 34, L20113, doi:10.1029/2007GL030368, 2007

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Observation of similar radio signatures at Saturn and Jupiter: Implications for the magnetospheric dynamics

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Received 13 April 2007; revised 23 August 2007; accepted 14 September 2007; published 31 October 2007.

[1] We report on radio signatures observed at Saturn by the Cassini RPWS experiment which are strikingly similar to the Jovian "energetic events" observed by Galileo. They consist of sudden intensifications of the auroral radio emission (SKR) followed by the detection of a periodic narrowband radiation which most likely originates from Saturn's plasma disk. About ten "events" have been observed in 2006, showing on average temporal scales ~3 times longer than their Jovian counterparts. We analyze the conditions of generation and the visibility of the narrowband radiation and conclude that the Kronian "events" are most likely associated with plasma evacuation from the disk. These observations provide new insights on the role of internal energy releases in Saturn's magnetosphere, known from other observations to be mainly driven by the solar wind. **Citation:** Louarn, P., et al. (2007), Observation of similar radio signatures at Saturn and Jupiter: Implications for the magnetospheric dynamics, *Geophys. Res. Lett.*, *34*, L20113, doi:10.1029/2007GL030368.

1. Introduction

[2] The dynamics of Saturn's magnetosphere is often considered to be intermediate between the terrestrial and Jovian ones. Many observations indicate that it is driven by the solar wind, as at Earth. For example, its auroral radiation (the SKR) is known to be correlated with the solar wind dynamic pressure [*Desch*, 1982], which has been directly measured using combined HST and Cassini observations [*Prangé et al.*, 2004; *Kurth et al.*, 2005]. The existence of Earth-like substorm at Saturn has also been reported [*Mitchell et al.*, 2005]. On the other hand, a large fraction of Saturn's inner magnetosphere is dominated by the rotation. It contains prolific plasma sources, which lead to the formation of a plasma disk [*Richardson and Jurac*, 2004; *Persoon et al.*, 2005; *Tokar et al.*, 2006]. Newly ionised particles are accelerated to co-rotation which thus continuously supplies rotational energy in this system. Jovian-like processes, involving radial plasma transport, interchange instabilities, energetic particle injections are then potentially important [*Cowley et al.*, 2005; *Mauk et al.*, 2005; *Hill et al.*, 2005; *André et al.*, 2005].

[3] With Cassini RPWS, remote radiations coming from different magnetospheric regions can be analyzed simultaneously which offers the possibility to survey the activity over the global scale and complements in-situ measurements. In the Jovian context, using Galileo PWS, *Louarn et al.* [1998, 2000, 2001] have shown that the magnetosphere is recurrently disturbed by large-scale "energetic events" that simultaneously increase the flux of the auroral emissions and create new sources of radiations in Io's torus. By comparing the disc density profiles measured before and after the "events," it was established that they correspond to sudden increases followed by more progressive decreases of the plasma content of the disc [*Louarn et al.*, 2000]. The "events" were interpreted as being the consequence of sporadic radial plasma transport and the associated release of rotational energy.

[4] We show that analogue radio signatures exist at Saturn (section 2) and describe them (section 3). We then examine whether they can be related to processes that, as at Jupiter, involve internal plasma transport (section 4).

2. Energetic "Events" at Saturn and Jupiter

[5] Figure 1 shows wave dynamic spectra obtained at Jupiter (Figure 1a) and Saturn (Figure 1b) by the Galileo PWS and Cassini RPWS experiments [*Gurnett et al.*, 1992, 2004]. Twenty days of observations are presented, beginning on September 18, 1996 and March 31, 2006, with spectra covering 20 kHz–5.6 MHz and 2 kHz–1 MHz, respectively.

[6] In Figure 1a a time period during which seven "energetic events" have occurred is presented. Above ~800 kHz, PWS detects an hectometric auroral radiation (HOM), similar to Earth's auroral kilometric radiation. The flux of such radiations is a good proxy of the magnetospheric activity [*Zarka*, 1998]. Below ~200 kHz, a narrowband emission (n-KOM) is detected, with a periodicity of ~10 hours. It is generated from sources that slightly subcorotate in Io's torus [*Reiner et al.*, 1993]. The "events" correspond to increases of the HOM flux (indicated by blue arrows) that are combined with a detection of new n-KOM sources (red arrows). These signatures correspond to major magnetospheric disturbances, observed with a quasi-period of 2 to ~10 days [*Louarn et al.*, 2000]. They are also

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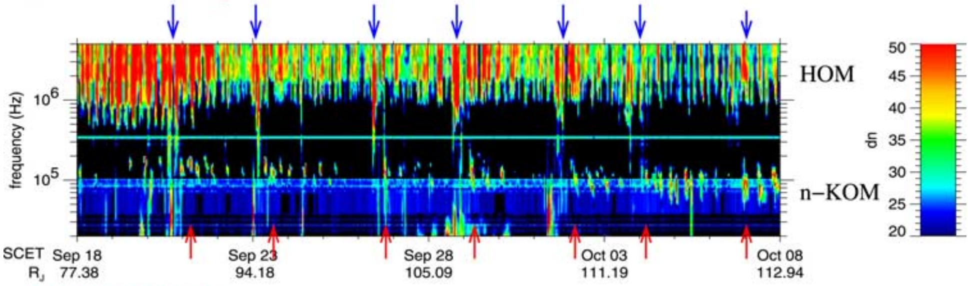
(a) Galileo PWS – Jupiter



(b) Cassini RPWS – Saturn

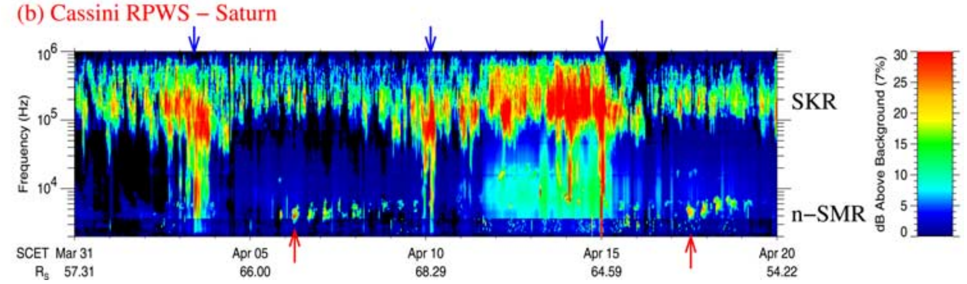


Figure 1. Galileo and Cassini radio observations of "energetic events," performed at ~90 Jupiter and ~60 Saturn radius, close to 24 h MLT and magnetic equator.

associated with bursts of MeV particles [*Woch et al.*, 1998; *Krupp et al.*, 1998], magnetic perturbations and inner magnetosphere particle injections [*Louarn et al.*, 2001].

[7] In panel (b), we present Cassini RPWS observations of similar radio signatures. Above ~80 kHz, one observes the Saturn kilometric radiation (SKR), an auroral emission very similar to HOM [*Zarka*, 1998]. It intensifies on April 3 and 14 by more than an order of magnitude, and somewhat less on April 10 (blue arrows). The intense increases of flux are followed by the apparition of a low frequency radiation (red arrows), at ~5 kHz, modulated at about Saturn's rotation period. This narrowband radiation was first identified by *Gurnett et al.* [1981]. It is reminiscent of the Earth's continuum coming from the plasmapause and the n-KOM from the Io torus. Given this analogy and its wavelength domain (more than 10 km), we propose to call it "n-SMR" for "narrowband Saturn Myriametric Radiation." Emissions of this type are known to be generated on density gradients [*Kurth*, 1992]. Incidentally, one may notice that both HOM and SKR present sporadic extensions to lower frequencies, down to 100 kHz and 2 kHz, respectively. These bursts coincide with the maximum flux of the auroral emission and can be considered as good markers of the occurrence of "events."

[8] The observation of such similar radio signatures suggests that similar processes, or chains of processes, operate in both magnetospheres. They associate auroral intensifications and the development of a specific activity that, as presented below, most likely takes place in the plasma disk.

3. Characteristics of Kronian "Events"

[9] During 2006, nine events have been identified when Cassini was relatively far from Saturn (r > 20 Rs), at (day/month): 02/04, 13/04, 04/05, 03/06, 21/07, 20/08, 15/09, 24/11 and 24/12. From this set, it is possible to deduce some general characteristics of the events, taking into account, however, that 2006 observations were made close to the equatorial plane. Seen from higher latitudes, the radio signatures could be different.

[10] First, the Kronian events are not as regular as the Jovian ones. They are separated by 20 to more than 30 days and we never record rapid quasi-periodic occurrences, of ~2–3 days, as at Jupiter. They also exhibit longer intrinsic time scales. Figure 2a is a rare Kronian case showing time scales similar the Jovian ones. The SKR intensification lasts ~15 hours, the associated n-SMR is then immediately detected and observed three times. A secondary SKR intensification occurs on September 18, a different n-SMR, with multiple sub-sources, being then detected. The time scales - the auroral intensification lasts for ~1 planetary rotation, with no delay in the detection of n-SMR which is observed ~3–6 times - are similar to Jovian ones. Events shown in Figures 2b and 2c appear to be more representative of the Kronian situation. The SKR intensifications last ~30 and ~60 hours, the first n-SMR occur ~30 and ~70 hours after the start of the SKR intensification and more than 9 spots of n-SMR are observed. These temporal scales are on average ~3 times longer than the Jovian ones. This may be related to intrinsic differences in the time scales of inner magnetospheric processes at Jupiter and Saturn.

[11] To progress, we will assume that the n-SMR is generated in the inner magnetosphere, on density gradients. Here, it is interesting to note that radio tones, with spectra similar to those of n-SMR, have been observed at the inner edge of Saturn's plasma disk [*Farrell et al.*, 2005; *Gurnett et al.*, 2005]. It is of interest to investigate whether the modulation of the radiation is synchronous with corotation. This technique indicates that Jovian n-KOM sources significantly sub-corotate, as expected since they are in the outer part of Io's torus. We cannot report that n-SMR modulation is significantly slower than Saturn's period. Slight super-corotation (less than 10%) has even been observed. For example, in Figure 3, we present the n-SMR integrated flux

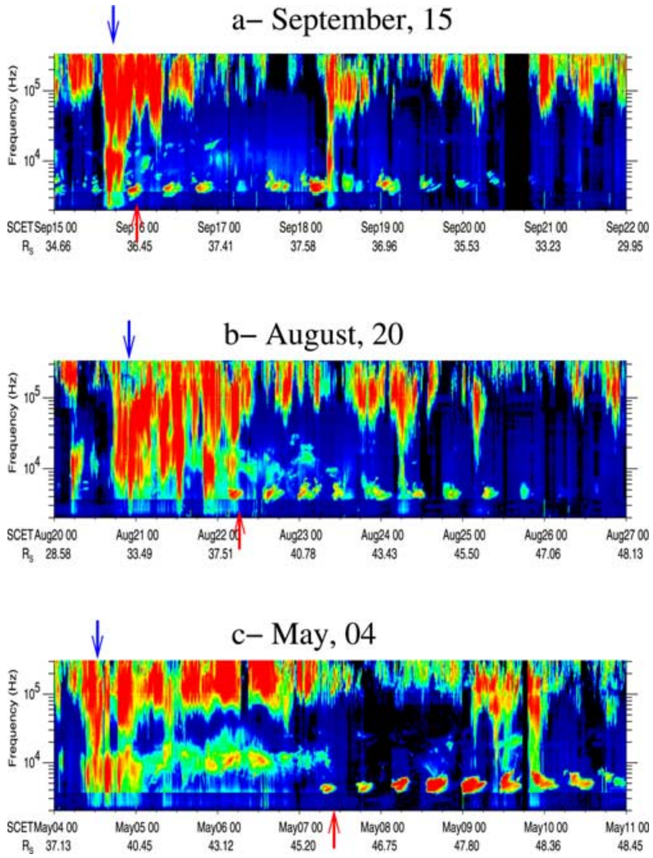


Figure 2. Examples of Kronian "events." Time periods of 7 days are shown, from 2 to 300 kHz. Cassini is at ~24 h MLT, ~30–40 Rs and latitudes below 15°.

as a function of Saturn longitude, for a few rotations following April 19 (event shown in Figure 1b). The systematical drift in longitude from one n-SMR pulse to the next one (indicated by the dashed line) is in the sense of super-corotation. According to models [*Saur et al.*, 2004], sub-corotation reaches 40% in the densest part of the disk (~4–10 Rs), sources in this region are therefore excluded.

[12] Another interesting observation concerns the visibility of n-SMR. Since late 2006, Cassini has been at larger latitudes (>30°) and has observed n-SMR more frequently. This effect has been quantified by a statistical analysis. We record the visual detection of n-SMR during each Saturn rotation. Considering only observations at r > 20 Rs, we obtain 215 detections during a total of 780 rotations, between January 2006 and February 2007. Of these, 147 detections during 507 rotations (proportion: 29%) occurred with Cassini at latitudes below 20°; 22 over 85 (26%) at latitudes from 20° to 40° and, 40 over 72 (56%) above 40°. The n-SMR is thus detected at least twice as frequently when Cassini is above 40°. This also means that it is more regularly generated than what would be deduced from low latitude observations only. A corollary is that the main effect of the events may be to enhance the visibility of n-SMR rather than to trigger it. Given its low frequency, the n-SMR is very sensitive to density variations. As discussed below, the visibility effect is thus probably related to some modifications of the density iso-surfaces of the plasma disk and/or plasmasheet.

4. Discussion and Conclusion

[13] For interpreting the "events," we have to reconcile the following points: (1) frequencies of n-SMR as low as 4 kHz implying densities below 0.3 cm^{-3}, in the region of generation (2) sources of n-SMR that corotate and even may super-corotate, and (3) variations in the visibility of n-SMR which, at low latitudes, is more easily detected after an "events."

[14] A first possibility (scenario 1) is to consider n-SMR sources in the outer part of the disk, at r > 10–12 Rs, where the equatorial density is below 1 cm^{-3} [*Persoon et al.*, 2005; *Richardson and Jurac*, 2004]. Further density decreases would then create conditions consistent the n-SMR generation. Interestingly, this could also offer the possibility to have sources in corotation. Indeed, as noticed by *Saur et al.* [2004], the magnetospheric conductance – a parameter linked to the friction between ions and neutrals – greatly influences the plasma rotation. This parameter decreases with the density. When very low densities and vanishing conductances are considered, the model shows that it is possible to restore corotation at r ~ 10 Rs.

[15] The other possibility (scenario 2) is to consider sources in the inner disk. *Gurnett et al.* [2005] have reported on an intense wave activity in the region of transition from super to sub-corotation of neutrals (r ~ 1.8 Rs). The density is there smaller than 0.1 cm^{-3} [*Wahlund et al.*, 2005] and electromagnetic waves, at n-SMR frequencies, are locally observed [*Farrell et al.*, 2005]. As sketched in Figure 4, these waves could access free space at large polar angles and explain the regular n-SMR detection from high latitudes. Their observation from low latitudes is, however, problematic. At best, if the n-SMR is generated along L-shells, as for the terrestrial continuum, emission from $|z| \sim 0.7$ Rs for L ~ 2 is possible. According to published density profiles, such waves, propagating parallel to the equatorial plane, would be tangent to the n = 30 cm^{-3} density surface

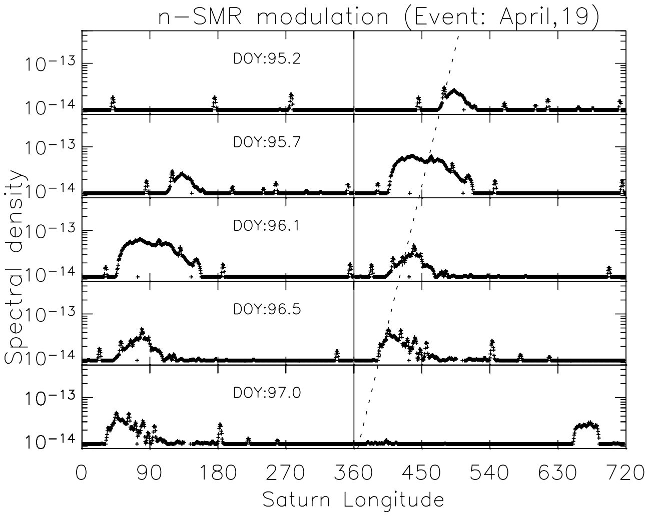


Figure 3. Example of longitudinal drift of n-SMR pulses. The n-SMR spectral density is averaged on 4–8 kHz.

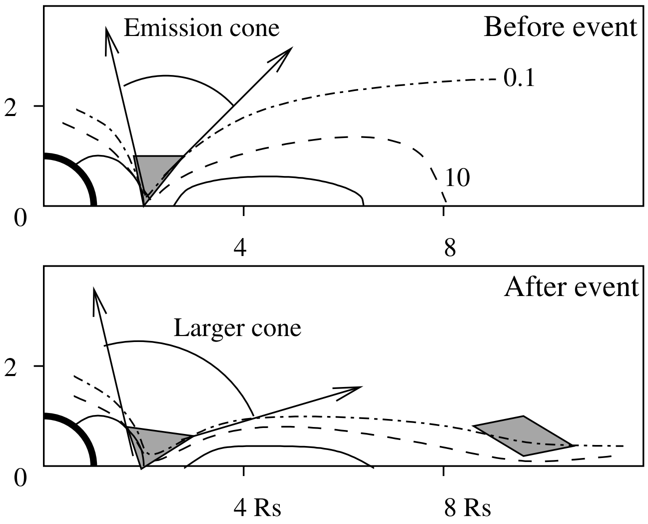


Figure 4. Sketch showing possible locations of n-SMR sources (in grey), in the external (scenario 1) and the inner parts (scenario 2) of the disk. Iso-density surfaces are indicated.

[*Persoon et al.*, 2005] and would not cross the densest part of the disk. Nevertheless, their observation from low latitudes still implies significant plasma evacuations from the external layers of the disk, typically at $|z| > 0.5$ Rs above or below the equatorial plane. The situation can be improved by considering the strong longitudinal modulation of the disk [*Gurnett et al.*, 2007]. Further transient evacuations from the depleted sector, where the minimal equatorial density is below 40 cm^{-3}, could create finger-like cavities in which the n-SMR could more easily access free space with propagation almost parallel to the equatorial plane.

[16] Scenario 2 is more demanding in terms of plasma transport than scenario 1. Let us assume that, globally, the external layers of the disk (region at $|z| > 0.5$ Rs) correspond to a disc of $\sim$10 Rs radius, $\sim$1 Rs thickness, 10 cm^{-3} density. Considering that the activity takes place in an longitude sector of $\sim$120° (which is consistent with the duration of n-SMR spots: $\sim$1/3 of Saturn's rotation period), $\sim$2.10^{32} particles would be evacuated. The plasma creation rates being of a few 10^{27} s^{-1} [*Richardson and Jurac*, 2004], this would concern less than 10% of ions created between events (during $\sim$30 days). The corresponding rotational energy is $\sim$10^{16} J, assuming that oxygen ions dominate. This energy is probably not simply dissipated since the plasma transport involves complex angular momentum transfers. However, this order of magnitude suggests that these internal processes may significantly contribute to the power dissipated in aurora (a few 10 GW) and complement the solar wind energy supply. For scenario 1, the estimate depends on the radial extension of the cavity formed in the outer edge of the disk. Assuming 1 Rs, the estimates made above would be reduced by $\sim$20 which still corresponds to a significant energy contribution.

[17] In conclusion, the radio signatures reported here suggest that Saturn's auroral activity, although largely triggered by the solar wind, also involves energetic processes developing in the plasma disk. We provide indications that they could well be associated with plasma transports and consequent releases of rotational energy. This remains to be firmly established, using particle data, for example. Concerning time scales, the difference in the recurrence rates has certainly to be related to the nature of the triggering: internal instability at Jupiter, external driver at Saturn. The reason for the Kronian "events" having time scales $\sim$3 times longer than the Jovian ones is an open question. It is indicative that the two magnetospheres have quite different intrinsic internal time scales and regulation mechanisms, perhaps related to a less efficient internal plasma and power supply at Saturn than at Jupiter.

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