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Analysis of a giant lightning storm on Saturn

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Abstract

On January 23, 2006, the Cassini/RPWS (Radio and Plasma Wave Science) instrument detected a massive outbreak of SEDs (Saturn Electrostatic Discharges). The following SED storm lasted for about one month and consisted of 71 consecutive episodes. It exceeded all other previous SED observations by Cassini as well as by the Voyagers with regard to number and rate of detected events. At the same time astronomers at the Earth as well as Cassini/ISS (Imaging Science Subsystem) detected a distinctive bright atmospheric cloud feature at a latitude of 35° South, strongly confirming the current interpretation of SEDs being the radio signatures of lightning flashes in Saturn's atmosphere. In this paper we will analyze the main physical properties of this SED storm and of a single small SED storm from 2005. The giant SED storm of 2006 had maximum burst rates of 1 SED every 2 s, its episodes lasted for 5.5 h on average, and the episode's periodicity of about 10.66 h exactly matched the period of the ISS observed cloud feature. Using the low frequency cutoff of SED episodes we determined an ionospheric electron density around 10^4 cm^{-3} for the dawn side of Saturn.

Keywords: Saturn; Lightning; Saturn, atmosphere; Radio observations

1. Introduction

Saturn Electrostatic Discharges (SEDs) are impulsive short-duration radio bursts that were detected by the PRA (Planetary Radio Astronomy) instruments onboard both Voyagers (Warwick et al., 1981, 1982) as well as by Cassini/RPWS in the vicinity of Saturn (Gurnett et al., 2005; Fischer et al., 2006). Intrinsically, SEDs have a large frequency bandwidth, but in the PRA as well as in the RPWS time-frequency spectra the single bursts appear as narrow-banded short streaks due to the fact that they are detected only in the few channels being sampled in the frequency sweeping receiver during the short duration of the burst.

SEDs are generally organized in episodes with a duration of several hours occurring during consecutive Saturn rotations: They are recorded by the radio instrument when the supposed source is on the side of the planet facing the spacecraft, whereas no SEDs are detected when the source is below the radio horizon on the far side of Saturn. Table 1 shows all SED storms recorded so far by the Voyagers and Cassini indicating their identifying name, the time when they were recorded, the number of SEDs and episodes, plus the episode's recurrence period. Most of the SED storms in this table show a clear episodical on–off behavior. The recent giant SED storm E was such a storm with very distinct episodes occurring at each of 71 successive Saturn rotations, and there were no SEDs in-between the episodes. Only the SED storms V2 (Voyager 2, August 1981) and D (Cassini, June 2005) were not so clear in this respect with SEDs occurring also between episodes or episodes with a duration significantly longer than half a Saturn rotation, suggesting either a longitudinally extended source or more than one source at the same time.

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Table 1
Summary of all SED storms detected by radio instruments on Voyager (V1, V2) and Cassini (0 to E)

Name	Date	SEDs and episodes	Recurrence period
V1	Mid November 1980	18000 SEDs in 16(?) episodes	10 h 09 min (±6 min)
V2	End of August 1981	5000 SEDs in 10(?) episodes	10 h 00 min (±7 min)
0	End of May 2004	100 SEDs in 8 episodes	10 h 35 min (±6 min)
A	Mid July 2004	800 SEDs in 15 episodes	10 h 43 min (±2 min)
B	First half of August 2004	300 SEDs in 16 episodes	10 h 40 min (±2 min)
C	Throughout September 2004	4200 SEDs in 49 episodes	10 h 40 min (±1 min)
D	Mid June 2005	300 SEDs in 6 episodes	10 h 10 min(?) (±10 min)
E	January/February 2006	43400 SEDs in 71 episodes	10 h 39.8 min (±0.4 min)

Numbers were taken from Evans et al. (1981), Zarka and Pedersen (1983), and Fischer et al. (2006). Values for storm D (period is likely but questionable) and E are determined in this paper. The period for storm E was determined from DOY 25 to 49 (see Section 6). The numbers of episodes for V1 and V2 are not mentioned in the SED literature, Evans et al. (1981) display 16 episodes for V1 in their Fig. 2, and the value for V2 comes from looking at Fig. 4 in Zarka and Pedersen (1983), but there is no clear episodical on–off behavior for V2 episodes.

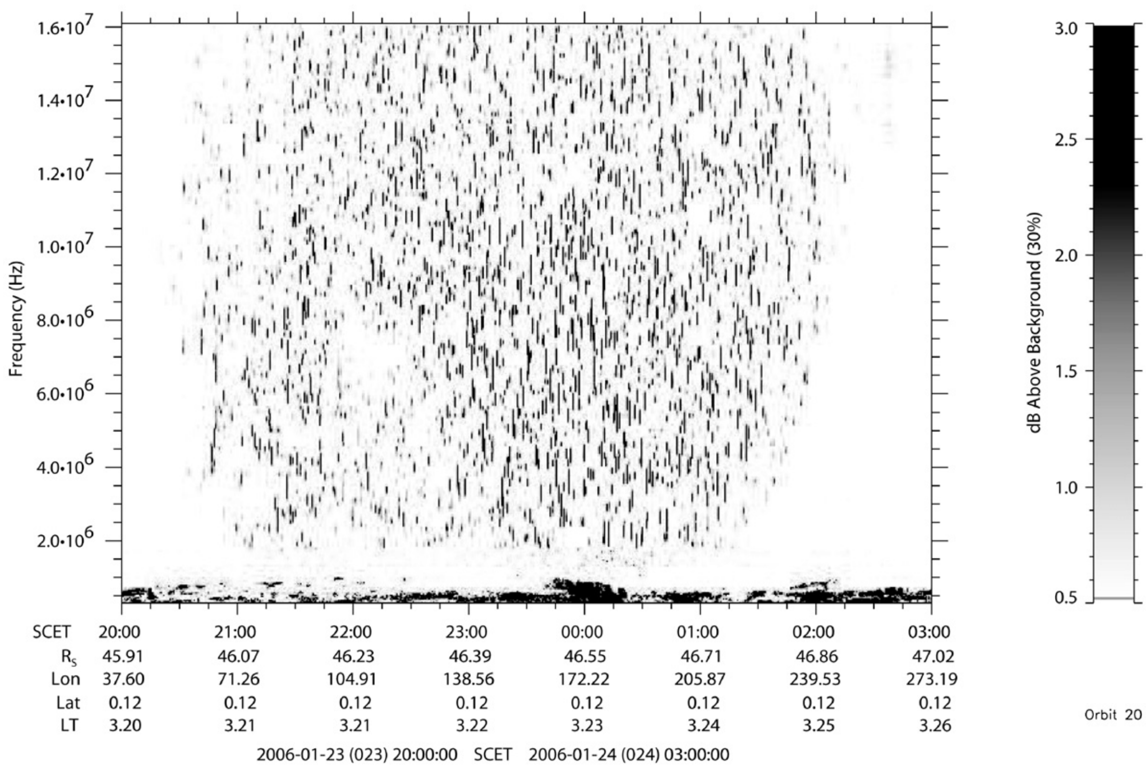

Fig. 1. Dynamic spectrum (intensity as function of time and frequency) over 7 h from 300 kHz to 16 MHz showing SED episode E2 from DOY 23/24, 2006. Orbital parameters of Cassini including distance in Saturn radii, sub-spacecraft western longitude, latitude, and local time are also indicated on the abscissa.

Fig. 1 shows the dynamic spectrum of the second episode of the giant SED storm from early 2006 with more than 4000 SEDs (the short vertical streaks), which is close to the number of all SEDs recorded during the whole storm C of September 2004. In contrast to the big SED storm E, the previous storm D from June 2005 consisted of just 6 episodes and lasted for about a week implying that SEDs did not show up during each rotation of Saturn. No other SED activity could be detected during the remainder of 2005, so there was a time gap of more than 8 months between storm C from September 2004 to the June 2005 storm, and a gap of 7 months to the next SED storm E in early 2006. No other SED activity besides storm E was detected by RPWS in 2006.

In this paper we will present the temporal occurrence of storms D and E, look at the duration of episodes and single bursts, and determine the burst rates and episode recurrence periods. First, there is a very brief description of the instrument and the data analysis method. Furthermore, we will show the intensity distributions of some SED episodes and we will look at the low frequency cutoff of SED episodes which shows an interesting behavior (see also Fig. 1) due to different viewing angles and ionospheric conditions. In the discussion we will emphasize that SEDs are the radio signatures of lightning from atmospheric storms at Saturn, which is supported by the images of cloud features provided by Cassini ISS (Imaging Science Subsystem).