GEOPHYSICAL RESEARCH LETTERS, VOL. 38, L08206, doi:10.1029/2011GL047316, 2011

The search for Titan lightning radio emissions

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Received 1 March 2011; revised 24 March 2011; accepted 29 March 2011; published 28 April 2011.

[1] We report on the non–detection of radio emissions indicative of Titan lightning by the Cassini RPWS (Radio and Plasma Wave Science) instrument. A previous study by Fischer et al. (2007) investigated the first 35 Titan flybys, and here we continue our search until the end of Cassini's equinox mission. No bursts that would clearly indicate the existence of Titan lightning were found. Great care is needed in the interpretation of bursty signals since spacecraft interferences, Jovian decametric arcs, solar radio emissions, and enhanced background fluctuations can sometimes mimic lightning bursts. During several Titan flybys the strong radio emissions of Saturn lightning were detected which can be distinguished from potential Titan lightning since they don't fall off in intensity with increasing distance to Titan. We show an example of an occultation of the Saturn lightning radio source by Titan.

Citation: Fischer, G., and D. A. Gurnett (2011), The search for Titan lightning radio emissions, *Geophys. Res. Lett.*, *38*, L08206, doi:10.1029/2011GL047316.

1. Introduction

[2] The existence of lightning on Saturn's enigmatic moon Titan has been suggested soon after the Voyager 1 flyby in 1980, and *Borucki et al.* [1984] found that Titan lightning could produce significant quantities of HCN, C_2N_2 and soot particles in the lower atmosphere. Although Titan lightning has not yet been discovered, its potential effect on atmospheric chemistry is still investigated today. *Kovács and Turányi* [2010] simulated the chemical reactions in Titan's troposphere during lightning with a detailed reaction kinetic analysis and identified the main chemical products. *Plankensteiner et al.* [2007] consider Titan lightning as a possible energy source for the production of organic compounds that could be essential as precursors for an evolution of life. They included the surface water ice in the reaction scenario leading to oxygenated compounds that are relevant for the formation of amino acids.

[3] Data from the in–situ Huygens Probe is still investigated with ambiguous results with respect to lightning activity. There are unidentified impulsive signals in the frequency range up to 11.5 kHz in the data of the Huygens Atmospheric Structure Instrument (HASI) that could be due to lightning according to *Fulchignoni et al.* [2005]. *Grard et al.* [2006] found no thunder clap recorded by the acoustic sensor and reported the observation of an electric signal at 36 Hz throughout the descent. However, it could not be confirmed if this emission was caused by lightning exciting a Schumann resonance in the ionospheric cavity. In a further investigation *Béghin et al.* [2009] concluded that the 36 Hz signal was created in Titan's upper ionosphere by a plasma instability mechanism. *Morente et al.* [2008] claimed the extraction of six Schumann resonances in agreement with their theoretical simulation from the HASI data, but *Hamelin et al.* [2009] rejected their technique as erroneous. *Béghin et al.* [2009] applied the technique of *Morente et al.* [2008] to Huygens cruise test data and retrieved the same results as those obtained during the descent, so there seems to be no clear evidence of Titan lightning in the Huygens data.

[4] *Desch and Kaiser* [1990] showed that no radio emissions indicative of Titan lightning were found with Voyager's radio instrument. *Fischer et al.* [2007] searched for evidence of Titan lightning in the RPWS data of the first 35 close Titan flybies and found nothing. In this paper we continue this search until the end of Cassini's equinox mission in autumn 2010 which brought the number of Titan flybys up to 72. We will discuss the existence of Titan lightning in view of the most recent Titan cloud observations.

2. Searching for Radio Emissions Indicative of Titan Lightning

2.1. Analysis of High-Frequency (HF) RPWS Radio Data

[5] To find Titan lightning we use data of the HF1 and HF2 bands of the High Frequency Receiver (HFR) of the RPWS instrument [*Gurnett et al.*, 2004]. The frequency range of these two bands goes from 325 kHz to 16,125 kHz, and the HFR acts as a frequency sweeping receiver with an instantaneous bandwidth of 25 kHz. We examined the RPWS data for the close flybys T36 to T72 within a distance of 100 Titan radii based on an estimation of *Lammer et al.* [2001]. This means that our examination typically goes from 12–13 hours before to 12–13 hours after closest approach to Titan. The exact instrument mode for most Titan flybys was already described by *Fischer et al.* [2007] and there were no changes for the T36 to T72 flybys. A computer algorithm was used for the extraction of bursty signals, and it mainly relies on an intensity threshold of 4 standard deviations (4σ) of the background fluctuation. It is the same algorithm that is used for the detection of Saturn lightning, and it is described in detail by *Fischer et al.* [2006].

[6] To reach the RPWS antennas on–board Cassini, potential Titan lightning radio signals have to pass Titan's ionosphere. An analysis of Voyager data from 1980 by *Bird et al.* [1997] and new Cassini radio occultations by *Kliore et al.* [2008] have provided concurrent results for the electron density altitude profile of Titan's ionosphere. Both works revealed a main ionospheric peak at an altitude near

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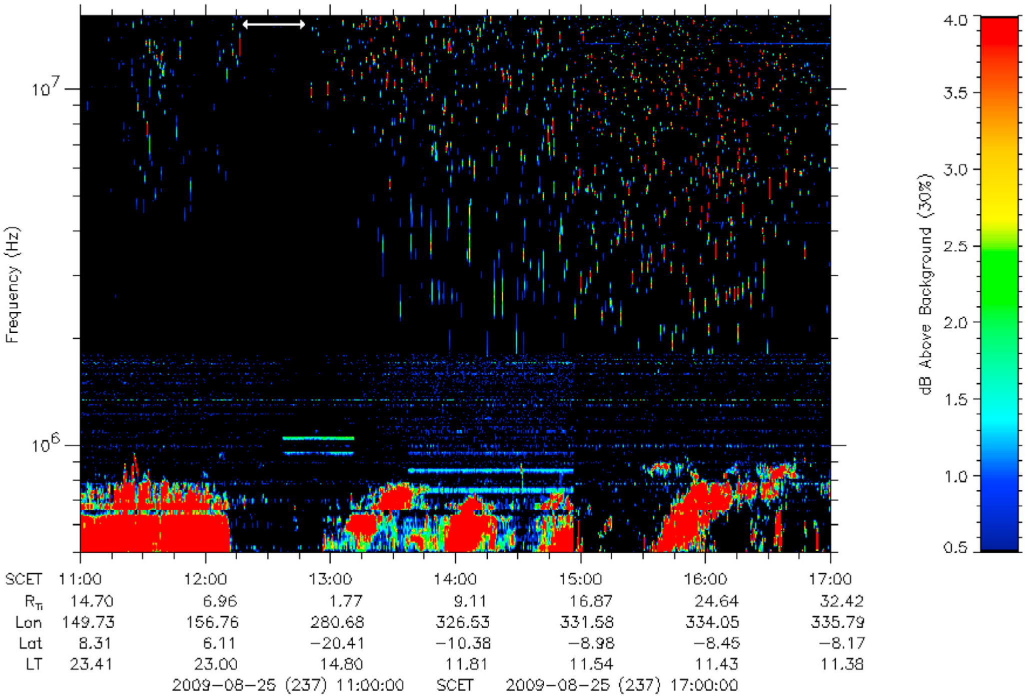

Figure 1. Dynamic spectrum of RPWS data during Titan flyby T61 on August 25, 2009. The color–coded intensity of radio emissions is plotted as a function of time (over 6 hours) and frequency (logarithmically from 500–16,125 kHz). Orbital parameters with respect to Titan (distance, longitude, latitude, local time) are also given with closest approach at 12:50 SCET. The continuous emission below 1 MHz is Saturn kilometric radiation, and the vertical bursts at higher frequencies are due to Saturn and not due to Titan lightning. The time during which the Saturn lightning source was occulted by Titan is indicated by a white arrow.

1200 km with electron densities of 1000–3000 cm^{-3}. This corresponds to plasma frequencies of 280–490 kHz, below which ordinary mode radio signals cannot propagate through the ionosphere. It is questionable if possible lightning whistlers could cross the ionospheric barrier on Titan due to the low magnetic field (<5 nT) and high collision frequencies [*Béghin et al.*, 2009]. The situation of Titan in Saturn's magnetosphere could be comparable to that of Venus in the interplanetary magnetic field, where *Russell et al.* [2008] interpret whistler mode signals measured close to Venus as due to atmospheric lightning. A systematic investigation of ELF (extremely low frequency) radiation close to Titan has not been performed yet, and in this paper we just focus on possible lightning spherics above the ionospheric cutoff frequency.

[7] The new Cassini radio occultation data has also shown a second more variable peak in the region of 500–600 km with similar densities [*Kliore et al.*, 2008]. Radio occultation measurements can provide the electron densities only around local dusk or dawn or at polar latitudes, and one can expect somewhat higher densities on the day side and lower densities on the night side. Since some Cassini flybys went down to a level of 950 km, the main peak at 1200 km was also measured in–situ by the Langmuir Probe. *Wahlund et al.* [2005] published a peak value of 3800 cm^{-3} obtained during the TA flyby on October 26, 2004, at a Titan local time around 16 hours. This means that above 550 kHz the ionosphere should be no obstacle for potential radio emission of Titan lightning if there is no substantial attenuation. In practice it is nearly impossible to identify Titan lightning below ~1 MHz since this frequency range is dominated by an overwhelming presence of Saturn kilometric radiation (SKR).

2.2. Saturn Lightning During Titan Flybys

[8] The detection of Titan lightning should be easy in the frequency range of 1–16 MHz if it exists and its intensity is high enough. If it is as intense as Earth lightning, we know from the Cassini Earth flyby that its signals would be about 40 dB above the background intensity around closest approach [*Gurnett et al.*, 2001], and it would be detectable within 35 Titan radii corresponding to the Earth lightning detection distance of 14 Earth radii. At Saturn, the most prominent radio emissions in this frequency range are Saturn Electrostatic Discharges (SEDs) caused by lightning storms in Saturn's atmosphere. Figure 1 shows such an episode of Saturn lightning recorded during Titan flyby T61 in a time–frequency spectrogram with color–coded intensity. There are several arguments that the small vertical bursts are due to Saturn lightning and not Titan lightning. First, Figure 2 shows that there is no decrease in burst intensity with increasing distance r to Titan where one would expect a $1/r^2$ decrease for an emission originating from Titan. We have indicated such a quadratic fall–off in intensity with two lines in Figure 2. The solid line assumes a burst intensity of 40 dB at 0.4 Titan radii (~1000 km), corresponding roughly to the intensity of Earth lightning measured by Cassini from a similar distance [*Gurnett et al.*,

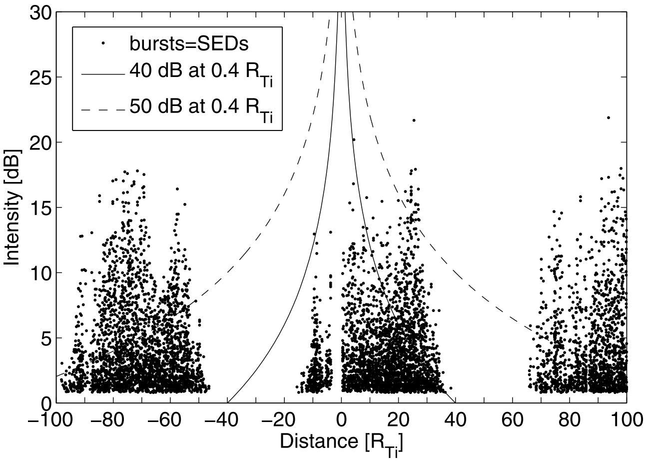

Figure 2. Intensity of impulsive bursts during flyby T61 as a function of distance r to Titan (in Titan radii R$_{Ti}$ with $r < 0$ for inbound and $r > 0$ for outbound). Since there is no fall–off with distance ($\sim 1/r^2$) as indicated by the two lines, we conclude that the bursts originate from Saturn and not Titan lightning. The episode around closest approach (see Figure 1) has a gap due to occultation of the SED source.

2001]. The dashed line assumes a higher intensity of 50 dB at a distance of ~1000 km resulting in a larger detection distance. The bursts in Figure 2 seem to have a relatively constant intensity. It cannot be totally excluded that a few burst during SED episodes are also due to Titan lightning, but for the episodes as a whole the intensity argument is definitely valid. Second, the Cassini cameras [*Porco et al.*, 2004] and ground–based observers detected a storm cloud at a latitude of 35° south in Saturn's atmosphere. At the time of the Titan flyby T61 (August 25, 2009), this storm was approximately located at a western longitude of 12.3° (Voyager Saturn Longitude System, SLS) and drifted only by 0.22° per day to the west. Eight days before, this Saturn lightning storm had been observed by the Cassini cameras at a western longitude of 10.6° on the night side of Saturn emitting visible flashes [*Dyudina et al.*, 2010]. The fast rotation of Saturn leads to an episodic on–off behavior of SED episodes with a period around 10 hours 40 minutes when the storm is rotating in and out of the view of the spacecraft. One can easily predict the sub–spacecraft western longitudes and times when the SED episodes should start and end, and the episodes around T61 are a good match to that prediction. There were several hundred SED episodes related to a Saturnian lightning storm that lasted from mid–January to mid–December 2009. The third argument is special only for this Titan flyby. It provides an explanation for the cessation of SEDs for about half an hour before closest approach at 12:50 SCET (Spacecraft Event Time) which is simply due to the occultation of the SED source by Titan. It can be seen in Figure 1 that the SKR source is occulted as well. A geometrical calculation shows that Titan's body occulted the SED source from 12:18 to 12:48 SCET (indicated by the white arrow in Figure 1), consistent with what is observed for SED frequencies above ~8 MHz. It is interesting to note that for smaller frequencies the occultation seems to last longer. It is possible that SED radio waves with frequencies of a few MHz are refracted by Titan's ionosphere and therefore cannot reach the spacecraft. There were 4 other Titan flybys (T43, T58, T67, T68) with an occultation of the SED source by Titan. However, these occultations could not be so clearly identified in the data due to their short duration and/or low SED rates.

[9] Besides T61, SEDs were also observed within 100 Titan radii during the Titan flybys T38, T39, T40, T41, T42, T43, T44, T47, T48, T50, T51, T52, T53, T55, T56, T57, T58, T59, T62, T63, T67, T68, T69, and T70. (There are SEDs beyond 95 R$_{Ti}$ at T60 outbound, but most of the data during this flyby was lost.) In all those cases the bursts appeared in the right phase with respect to the observable Saturn lightning storm. We made plots similar to Figure 2 for all Titan flybys, but no fall–off in intensity as function of distance to Titan could be identified. The SED episodes usually happen during both inbound and outbound trajectory of Cassini with respect to Titan. Lightning bursts from a storm system on one side of Titan should usually be detectable just during one part of the trajectory (inbound or outbound) due to the slow rotation of Titan. There are several Titan flybys with no disturbing SEDs at all. Saturn lightning activity was absent around the first 35 Titan flybys TA–T35 (October 2004 until August 2007). The SEDs of 2004 [*Fischer et al.*, 2006] happened before TA and a one month long lightning storm in January/February 2006 took place between T10 and T11.

2.3. Other Radio Emissions and Interferences Above 1 MHz

[10] Besides SEDs there are other types of radio emission detectable at Saturn above 1 MHz that have been already discussed by *Fischer et al.* [2007]. There are solar type III bursts or Jovian decametric arcs that usually last for several minutes and can be identified as patchy emissions in the dynamic spectrum. But, with a low intensity they can also mimic the spectral appearance of lightning bursts. Occasionally there are high–voltage discharges between the plates of the Ion and Neutral Camera (INCA) that cause bursty emissions above ~10 MHz. A few channels of the HFR (e.g., 2,425 kHz or 15,025 kHz) sometimes show a somewhat bigger background fluctuation which has to be taken into account by increasing the threshold for these channels. There is a certain probability that a few bursts per day (depending on the HFR mode and number of measurements) exceed the applied 4σ–threshold, but still are just due to the natural fluctuation of the background [*Fischer et al.*, 2006]. This is what we mean by bursts caused by an enhanced background fluctuation. Solar bursts and INCA discharges were illustrated in Figure 1 of *Fischer et al.* [2007] when they occurred during the Titan flybys TA and TB, respectively. It follows that due to all these radio emissions, a positive identification of Titan lightning still needs great care. We only found a few weak sporadic bursts which we could not clearly attribute to one of the mentioned emissions. However, we should demand at least a few dozen of intense bursts with a clear fall–off in intensity with distance to Titan for a positive identification of Titan lightning.

[11] For T36–T72 (October 2007 until September 2010) solar burst occurred during T46 and T54, and there were two very small events during T42 and T66. Solar radio emissions were relatively rare in this time interval due to the low solar activity. Similarly, Jovian radio emission were hardly seen at all due to the large distance of Jupiter (~12.4 to

14.5 AU). They possibly occurred during T52 and T56. The INCA discharges were clearly present during the flybys T61, T62, and T72. They were only weak during T58, T59, T64, T65, T66, T69, and T71.

3. Discussion

[12] Lightning could be present on Titan even without detection of HF radiation. An example for this is Jupiter, where lightning has been clearly identified optically and by measurements of whistlers, but no HF radio component has been detected by the radio instruments of the Voyagers, Galileo, Ulysses or Cassini. There are two possible reasons for that, one is the absorption of HF radio waves by Jupiter's ionosphere [*Zarka*, 1985], and the other is that Jovian lightning might be a slow discharge [*Farrell et al.*, 1999] that emits only very weak HF radiation. Both scenarios are also conceivable for the absence of HF radiation of possible Titan lightning.

[13] It is natural to look for convective clouds on Titan as possible source location for lightning. *Tokano et al.* [2001] developed a thundercloud model in which moist convective clouds could possibly be charged by large amounts of free electrons. *Rodriguez et al.* [2009] and *Brown et al.* [2010] identified three main cloud regions on Titan using data of the Cassini Visual and Infrared Mapping Spectrometer (VIMS). Cloud activity mainly occurs at the north and south pole and at southern midlatitudes around 40°. The north polar cloud appears spatially and temporally uniform and is most likely caused by the subsidence and condensation of ethane into the colder troposphere [*Griffith et al.*, 2006]. Such a stratiform cloud is no likely place for lightning, but *Brown et al.* [2009] also detected convective lake–effect clouds at high northern latitudes. The transient southern mid–latitude clouds are mostly elongated in the east–west direction and appear to be convective as well [*Griffith et al.*, 2005]. The strongly convective clouds on Titan's south pole occurred mainly in 2004 and from October 2006 until July 2007, but no Titan lightning radio emissions could be identified by *Fischer et al.* [2007]. Cassini VIMS missed to spot a large scale equatorial cloud outburst that was detected from the ground by *Schaller et al.* [2009] in April and May 2008. *Griffith et al.* [2009] also detected smaller convective clouds with Cassini VIMS in tropical latitudes during 5 Titan flybys. These tropical clouds remain at altitudes below 26 km whereas the high latitude clouds often reach altitudes up to 45 km. *Schaller et al.* [2009] note that so far three big outbursts of cloud activity on Titan were detected, the first one in September 1995 at low latitude, the second one was the large outburst of Titan's south pole cloud from October 2004, and the third one the low latitude clouds of April/May 2008. Cassini's Titan flyby TA caught the October 2004 outburst only in a dissipating stage, and the same is true for the April/May 2008 outburst where only remnants could be spotted during T43 and T44. Just recently, the Cassini imaging team announced the detection of a large equatorial cloud imaged on September 27, 2010, on their web page (http://www.ciclops.org/view_event/142/Titan_Rev_138_Raw_Preview?js=1). However, RPWS did not detect lightning radio signals during flyby T72 three days before.

[14] *Tokano et al.* [2001] noted that one should not rush to a conclusion concerning the likelihood of lightning on Titan if one does not find lightning events during a short observation period. However, Cassini has now spent more than 600 hours (25 days) within the possible lightning detection distance of 35 Titan radii.

4. Conclusion

[15] The search for HF radio signals indicative of Titan lightning still brought no positive result after 72 close Titan flybys during Cassini's nominal and equinox mission. Lightning on Titan is probably a very rare event if it exists at all. Since there are rare outbursts of strong convective cloud activity in Titan's atmosphere, it is advisable to continue the search.

[16] **Acknowledgments.** G. F. was supported by a grant (P21295–N16) from the Austrian Science Fund (FWF). The research at the University of Iowa was supported by NASA through contract 1356500 with the Jet Propulsion Laboratory.

[17] The Editor thanks Robert West and an anonymous reviewer for their assistance in evaluating this paper.

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