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Nondetection of Radio Emissions From Titan Lightning by Cassini RPWS

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Key Points:
- All Cassini Titan flybys were examined for radio emissions from Titan lightning
- No radio emissions from Titan lightning were found in Cassini RPWS data
- New upper limits for potential but unlikely Titan lightning activity were set

Supporting Information:
- Supporting Information S1

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Abstract The Saturn-orbiting Cassini spacecraft completed 126 close Titan flybys from 2004 until 2017. During almost all of them the Cassini Radio and Plasma Wave Science (RPWS) instrument was turned on to search for radio emissions attributed to Titan lightning. Here we report about their nondetection after close inspection of all Titan flybys throughout the Cassini mission. We also infer new and strong constraints on the permissible flash energy and flash rate of potential Titan lightning. The nondetection of lightning flashes by Cassini observations implies that any lightning on Titan must be either very weak, very rare, or does not exist at all, and the latter could be due to cloud electric fields being too low to initiate a discharge. This finding holds important implications for the prebiotic chemistry of Titan and also implies that lightning will not be a significant hazard to the upcoming Dragonfly mission.

Plain Language Summary During its Saturn tour the Cassini spacecraft performed 126 close Titan flybys. The RPWS (Radio and Plasma Wave Science) instrument would have been able to detect radio emissions from potential lightning in Titan's atmosphere, similar to the easy detection of Earth lightning during the Cassini Earth flyby in August 1999. A careful inspection of RPWS data has revealed no radio signals that could be attributed to Titan lightning. The long observation times make it very likely that Titan lightning does not exist, is very weak, or is very rare.

1. Introduction

The search for lightning in Titan's thick, nitrogen-dominated atmosphere started with the flyby of Voyager 1 at Saturn's largest moon in November 1980. Since then, several theoretical and experimental studies have been published in the literature about the plausibility of lightning at Titan. The interest in the subject can largely be explained by the hypothesis that Titan lightning would provide an energy source for the creation of various chemical substances like HCN, C_2N_2 (Borucki et al., 1984, 1988; Kovács & Turányi, 2010) or even organic compounds that could be essential precursors for the creation of life (Plankensteiner et al., 2007).

No definite signal of Titan lightning has been detected by Voyager 1, the Cassini orbiter or the Huygens Probe, neither optically, acoustically, chemically nor by radio emissions at various frequencies. Despite the fact that the Huygens Probe microphone detected no thunder clap (Grard et al., 2006), Petculescu and Kruse (2014) still assessed the detectability of Titan lightning by acoustic sensing. Fulchignoni et al. (2005) showed an extremely weak and unidentified signal in the VLF range (1–10 kHz) at a time of 2,800 s in their Figure 8b measured by the Huygens Atmospheric Structure Instrument (HASI), but Hamelin et al. (2011) noted that no particular emission was recorded in the VLF range. There was a debate about the 36 Hz signal detected by HASI to be a lightning-induced Schumann resonance (Hamelin et al., 2009; Morente et al., 2008), but it was shown that the signal should have been created by electric currents induced in Titan's ionosphere by Saturn's magnetospheric plasma flow (Béghin, 2014; Béghin et al., 2009, 2012). No optical lightning detection from Titan's nightside has been reported by the Cassini imaging team. Fischer et al. (2007) and Fischer and Gurnett (2011) had reported the nondetection of Titan lightning sferics by the Cassini Radio and Plasma Wave Science (RPWS) instrument in the HF (high-frequency) range after 35 and 72 close Titan flybys, respectively. Here we complete this search in RPWS data using all Titan flybys and approaches, and our result will be the same: There is no indication for Titan lightning in Cassini RPWS high-frequency data.

Table 1
List of Seven Approaches to Titan Not Classified as Flybys

Name	Year	DOY	Date	SCET	Altitude (km)
139TI	2010	287	14 October	17:06	172,784
228TI	2015	351	17 December	13:23	148,599
259TI	2017	032	1 February	19:52	219,437
261TI	2017	048	17 February	13:10	186,791
275TI	2017	144	24 May	00:18	117,956
288TI	2017	223	11 August	05:04	194,991
292TI	2017	254	11 September	19:04	119,733

2. Titan Flybys of Cassini

Cassini performed 126 targeted Titan flybys, which are named TA, TB, and T3 to T126. A first farther approach to Titan on 3 July 2004 named T0 is not classified as a close flyby. T0 is also not included in our lightning search since it was no closer than ~132 R_{Ti} (Titan radii). Our detailed search for Titan lightning in RPWS data was performed within a distance of 100 R_{Ti} from Titan's center (99 R_{Ti} or 255,000 km above the surface). Beyond that distance one would need a signal more than 10 times stronger than average terrestrial lightning (see section 4 and Figure 3) for detection, which is quite unlikely. All RPWS high-frequency data have been analyzed. Strong impulsive signals exist far from Titan, but they all can be attributed to lightning from Saturn. Cassini did not acquire science data from the instruments on the orbiter during flyby TC on 14 January 2005. Instead, it recorded the science data transmitted from the Huygens Probe during its landing operation on Titan. RPWS data were recorded during all Titan flybys except TC (Huygens Probe landing) and T73 when a data gap occurred. There is a large data gap at T60 where RPWS data are only taken on the outbound leg beyond ~93 R_{Ti}. Additionally, there are seven approaches to Titan within a distance of 100 R_{Ti} which are not classified as targeted flybys. We have listed them in the following Table 1, and their names are given by the official number of the Saturn orbit (“rev”) and the letters “TI” for Titan. This is the naming convention used in the mission catalog file of our data set in the NASA Planetary Data System (see the “Data Availability Statement” section). For example, the last approach to Titan named 292TI took place 3–4 days before the end of the mission, and it gave the spacecraft its final nudge to crash into Saturn's atmosphere. We also looked for Titan lightning during these approaches listed in Table 1.

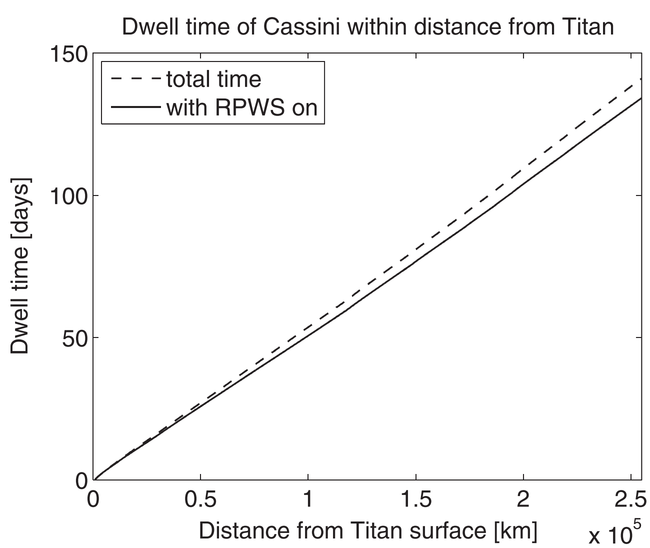

Figure 1. Dwell time of Cassini within various distances from Titan's surface.

During the entire Saturn tour Cassini spent ~141 days within a distance of 100 R_{Ti} from its center. During that time the Cassini RPWS instrument was on for ~134 days or ~95%. In total, Cassini spent ~100 min within 1,000 km of Titan's surface. The minimum distance was 878 km above Titan's surface, which was reached at T70 on 21 June 2010. Figure 1 shows the total dwell time of Cassini in days as a function of distance from Titan's surface. For each flyby Cassini spent on average ~27 hr within a distance of 100 R_{Ti}.

3. Natural and Artificial Radio Emissions Above Titan's Ionospheric Cutoff Frequency in Cassini RPWS Data

Titan has a complex ionosphere with a composition dominated by heavy, organic molecular ions. Its electron density peak is located at an altitude near 1,200 km with peak densities in the range from 500 to 4,000 cm^{-3} (Galand et al., 2014). The lower value corresponds to a plasma frequency of ~200 kHz and is the minimum for nightside conditions. The dayside maximum of up to 4,000 cm^{-3} means a cutoff by the plasma frequency of ~570 kHz. Cassini sometimes flew below the peak altitude, but electron densities measured by the Cassini RPWS Langmuir Probe still reached

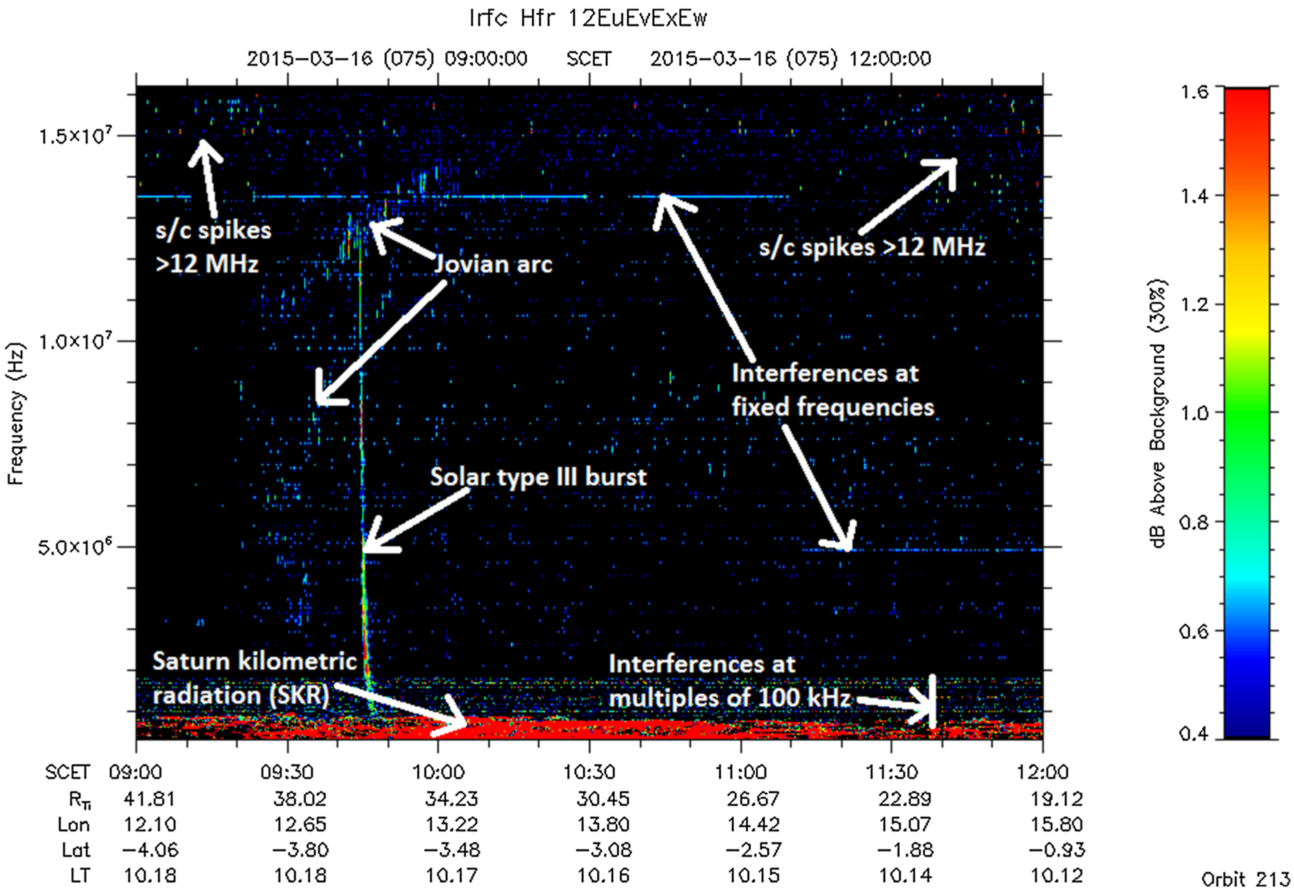

Figure 2. Cassini RPWS dynamic spectrum with multiple natural and artificial radio emissions during T110. Orbital parameters of Cassini below the Spacecraft Event Time (SCET) are given with respect to Titan (distance, longitude, latitude, and local time).

500 cm^{-3} at the nightside (Ågren et al., 2009). This means that it is highly unlikely that potential lightning sferics below a frequency of ~200 kHz could penetrate the ionosphere and reach the spacecraft.

To look for Titan lightning we used the HF1 and HF2 band of the RPWS high-frequency receiver (HFR) in which the HFR acts as a frequency-sweeping receiver (Gurnett et al., 2004). HF1 and HF2 can go down to 125 kHz, but HF1 typically starts at 325 kHz and HF2 at 1,825 kHz in the most common survey mode or at 4,025 kHz in the so-called direction—finding mode (see Appendix A of Fischer et al., 2019). The frequency range from a few tens of kHz up to 1,200 kHz is dominated by strong Saturn kilometric radiation (SKR), which makes it almost impossible to detect potential Titan lightning in this frequency range. At some close flybys the SKR is occulted by Titan, and then we made an additional visual check using a 1-hr-long dynamic spectrum centered around closest approach also including the C-band of the HFR which goes from 71 to 319 kHz. Dynamic spectra display the radio wave intensity as a function of time and frequency, and we display one in Figure 2 which shows strong SKR in red at the bottom. Besides the visual inspection of dynamic spectra within a distance of 100 R_{Ti}, we used the same numerical algorithm to look for Titan lightning as for the detection of Saturn lightning bursts, which has been described elsewhere (Fischer et al., 2007, 2019; Fischer, Desch, et al., 2006).

As mentioned previously, strong impulsive bursts caused by Saturn lightning have not only been registered during Titan flybys, but also occurred far from Titan. Lightning from Saturn (also called SEDs for Saturn electrostatic discharges) occurs in episodes with a typical 10–11 hr periodicity due to Saturn's rotation. Cloud features corresponding to the SEDs were generally found in Saturn's atmosphere (Fischer et al., 2008), and the SED intensities do not depend on the distance to Titan, but on the distance to Saturn (see Figure 7 in Fischer et al., 2019). Hence, it is straightforward to distinguish SEDs from potential Titan lightning, and the latter is practically impossible to detect during SED activity. In Figure 2 of Fischer and Gurnett (2011) we had shown the intensity of SEDs during T61 as a function of distance to Titan, and there was no obvious fall-off with distance squared. SED episodes occurred during the following 32 Titan flybys: T38–T44 (with marginal activity at T39) during the SED storm recently described by Fischer et al. (2019), T47 and T48 during an SED storm at the end of 2008, T50–T63 (except T54) during an SED storm that lasted for almost the whole year 2009, T67–T70 during an SED storm in 2010, T74–T77 during the Great White Spot in 2011, and finally T92 and T93 during a smaller storm in 2013.

Other natural radio emissions that can lead to false detections by our numerical algorithm are Jovian radio emissions that can be detected just a few dB above background by Cassini RPWS despite the large distance to Jupiter. This is due to their high intensity and the low sensing threshold of Cassini RPWS. In 2003 such Jovian radio emissions were misinterpreted as the first indication of Saturn lightning when Cassini was at a distance of 1.1 AU from Saturn (Fischer, Macher, et al., 2006). Sometimes Jovian emissions are easy to recognize by their arc-like shape in the dynamic spectrum, or they have a patchy appearance instead of isolated single bursts as one would expect for lightning. Sometimes it is helpful to look at the Io phase and the Jovian CML (Central Meridian Longitude) seen from Cassini to identify Jovian emissions since they have higher occurrence probabilities at certain Io phase/CML combinations (Imai et al., 2011). For example, the Jovian arc in Figure 2 has a CML of ~240° and an Io phase of ~195° pointing to a non-Io A emission. We believe to have identified Jovian radio emissions at the following 19 Titan flybys and approaches: TA, T3, T5, T10, T15, T19, T21, T32; T56; T103, T110, 228TI, T117, T119, T122, 261TI, T126, 275TI, and 292TI. With the single exception of T56, Jovian emissions were detected either earlier or later in the mission, which is related to the changing distance between Jupiter and Saturn. At T32 in June 2007 the distance between the two gas giants was ~12.0 AU and increasing with time to ~13.8 AU during T56 (June 2009). The maximum distance was reached in July 2011 at ~14.5 AU, and Jovian emissions began to reappear with T103 in July 2014 when the distance fell below ~12.7 AU.

The type III Solar radio bursts are quite easy to identify in a dynamic spectrum (see Figure 2) as almost vertical bursts covering all the high frequencies down to a few hundred kHz and lasting from a few seconds to some minutes. Sometimes isolated bursts of much shorter bandwidth also appear within 1 hr around the main burst. We have identified Solar bursts during 47 Titan flybys and approaches, which we don't list here in detail. Their occurrence also turns out to be related to the Solar cycle with only few cases from spring 2007 until early 2011 when the sunspot number was low. Exceptionally high numbers of Solar bursts were seen during T96 and T97 at the turn of the year 2013/2014 when the sunspot number was close to its peak.

There are also many different kinds of artificial radio emissions caused by interference from the spacecraft itself. Many of these are at fixed frequencies (e.g., at multiples of 100 kHz in the survey mode in HF1, see Figure 2) which make them easy to identify and the corresponding frequency channels can be eliminated. Occasionally, there are bursty emissions above ~10–12 MHz lasting for several hours which Fischer et al. (2007) and Fischer and Gurnett (2011) suspected as being caused by discharges of the INCA (Ion and Neutral Camera) instrument. We checked this again and found occasional relations between those bursts and the timing of the INCA ion Mode 1. However, it was no clear one to one relation, and so other instruments or spacecraft systems should play a role as well. Therefore, we labeled those bursty emissions as spacecraft (s/c) spikes in Figure 2. Most important, the intensities of such spacecraft spikes show no relation to the distance from Titan, thereby excluding Titan as the source.

In the supporting information we provide a list of all Titan flybys with the flyby name, time (year, day of year, date, and time of closest approach), local time at closest approach, altitude, and the natural and artificial signals mentioned above. These signals can lead to false detections by our numerical algorithm, which is based on the exceedance of an intensity threshold of 4 standard deviations (4σ) of the background fluctuation with respect to the background intensity and with respect to the intensity at adjacent frequency sweeps (see Section 3 of Fischer, Desch, et al., 2006). This means that great care and experience is needed for the identification of potential Titan lightning bursts. We usually excluded all the bursts of natural and artificial signals which were easy to identify in our list of potential candidate events. After that our list typically still contained a handful of unidentified bursts. Indeed, the 4σ threshold means that there is a probability of 0.00032% to have an intensity larger than the threshold. The number of HFR time/frequency measurements in the typical survey mode within 100 R_{Ti} for one Titan flyby is about 1.2 million (~200 measurements per sweep every 16 s). This means that on average one can expect ~4 bursts to exceed the 4σ threshold for each Titan flyby. We displayed the intensity of the unidentified bursts as a function of distance to Titan to see if there was a clear relation, but we *never* found one. Many unidentified bursts had intensities only slightly

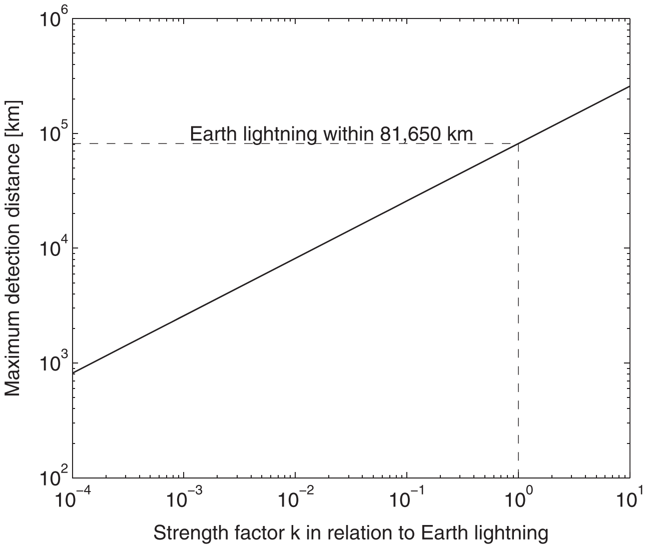

Figure 3. Cassini RPWS detection distance as a function of signal strength in relation to terrestrial lightning.

higher than the 4σ threshold and thus can be regarded as enhanced background fluctuations. Occasionally there were also stronger signals, but they usually were single events and could be sporadic SEDs, for example. We note that a clear indication of Titan lightning would be about a dozen bursts that roughly show a quadratic fall-off with increasing distance to Titan. The exceptional claim of the existence of Titan lightning thus also requires an exceptional proof. We emphasize again that we checked all Titan flybys and approaches and did *not* find a positive indication for Titan lightning.

4. New Upper Limits for Titan Lightning Activity

Desch and Kaiser (1990) have set an upper limit for potential Titan lightning activity based on the nondetection of Titan lightning by Voyager 1 during its single Titan flyby on 12 November 1980, when the spacecraft passed within 4,394 km of Titan's cloud tops. In their Figure 3 they have created a diagram showing the total flash energy versus the flash rate, and they marked a hatched area excluded by the Voyager 1 observation. We will construct a new version of this diagram here based on the nondetection of the Cassini spacecraft.

First, we make a few remarks on the detection distance of lightning signals. Since lightning radio emissions are almost isotropically beamed, they typically fall off in intensity I with distance d squared:

$$I = I_0 \left(\frac{d_0}{d} \right)^2 \tag{1}$$

For terrestrial lightning the radio noise at a distance of $d_0 = 1{,}000$ km was found to be $I_0 = 1.2 \times 10^{-13}$ $V^2\, m^{-2}\, Hz^{-1}$ at 10 MHz (Horner, 1965). Using this equation we now calculate the detection distance as a function of the strength of lightning which we give as multiples of I_0 from 0.001 I_0 to 10 I_0. The radio emissions from lightning can be detected if their strength is above the galactic background intensity of $I_{bg} = 1.5 \times 10^{-17}\, V^2\, m^{-2}\, Hz^{-1}$ (Dulk et al., 2001) plus a fluctuation of 4 standard deviations. For Cassini RPWS the most commonly used survey mode has a fluctuation of $4\sigma \approx 0.8$ dB, which means that our minimum detected intensity is $10^{0.08}\, I_{bg} \approx 1.2\, I_{bg}$. This gives the following relation:

$$kI_0 \left(\frac{d_0}{d_d} \right)^2 > 1.2 I_{bg} \tag{2}$$

with d_d as the detection distance and k the strength factor varying from 0.0001 to 10. This equation only needs to be inverted to give the relation between the detection distance d_d and the strength factor k as it is displayed in Figure 3. We also indicated the calculated maximum detection distance for Cassini RPWS for terrestrial lightning, which is around ∼82,000 km. This value is consistent with the detection distance of ∼13 Earth radii (14 Earth radii from the center of Earth) found for terrestrial lightning during the Cassini Earth flyby of August 1999 (Gurnett et al., 2001).

For each distance from Titan we know the lightning search time from Cassini's trajectory (see Figure 1), and so it is easy to relate the lightning search time t_s to the strength of lightning (factor k) in Figure 4. We just mentioned that for the detection of potential Titan lightning with the strength of Earth lightning ($k = 1$) Cassini needs to be within a distance of $d < 82{,}000$ km, and that was the case for a total of $t_S \sim 40$ days for all Titan flybys as one can see in Figure 4. Similarly, for weaker Titan lightning with a strength of only 1% of Earth lightning ($k = 0.01$) the detection distance is $d_d = 8{,}000$ km, and Cassini spent about 4 days within this distance from Titan.

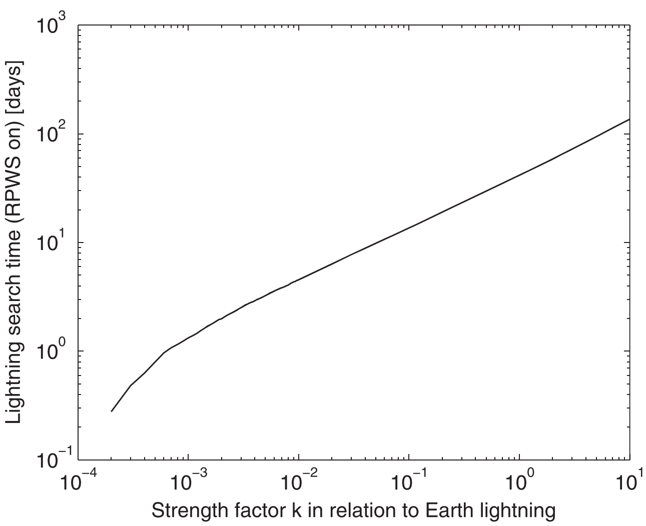

Figure 4. Cassini RPWS Titan lightning search time t_S in days as a function of signal strength in relation to terrestrial lightning.

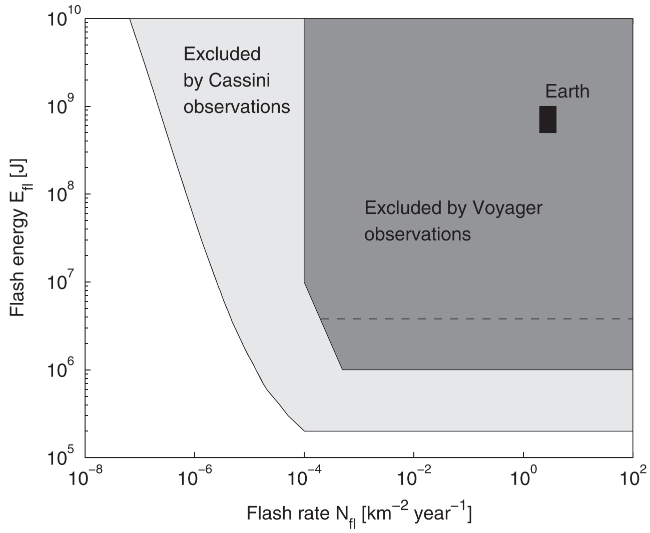

Figure 5. Energy of potential Titan lightning flashes E_{fl} versus their rate N_{fl} and various regions excluded by Voyager 1 and Cassini observations. The black square shows the flash energy and rate of typical Earth lightning. The dark gray region was excluded by Voyager observations after Desch and Kaiser (1990). The light gray region is the additional region to be excluded after the nondetection of Titan lightning by Cassini in this paper. The white region marks the flash energy/rate combinations which are left for potential Titan lightning, which must be either very weak or very rare. The dashed line is a factor of 20 above the lightning energy limit imposed by the Cassini observations, and it is explained in the text.

Using the lightning search time we can now give an upper limit for the flash rate N_{fl} using the following relation:

$$N_{fl} < \frac{1[\text{flash}]}{t_S[\text{year}]A\,[\text{km}^2]} \tag{3}$$

where A is the area on Titan seen from the position of Cassini. The relation is based on the fact that we did not detect any Titan lightning so that the number of detected flashes is smaller than 1. The flash rate N_{fl} is often given in units of flashes per kilometer squared and year, which is indicated in the equation above. For the area A it is possible to give the following relation depending on the altitude d of Cassini above Titan's surface:

$$A = 2\pi R_{Ti}^2 \frac{d}{d + R_{Ti}} \tag{4}$$

with $R_{Ti} = 2{,}575$ km as Titan's radius, which is assumed to be spherical. With these relations it is now possible to construct a diagram of the maximum flash rate N_{fl} as a function of the strength of lightning (factor k) since we know the search time t_S as a function of k (Figure 4) and the detection distance as a function of k (Figure 3). For a comparison with the original figure of Desch and Kaiser (1990) we translate the strength of lightning (factor k) to the total flash energy E_{fl} in Joules by assuming that its radiated power flux I (Equation 1) is proportional to the total flash energy E_{fl} and that the average terrestrial flash with $k = 1$ has an average total energy of $E_{fl} = 10^9$ J. We also exchange the ordinate with the abscissa, and so we get a plot of the flash energy E_{fl} as a function of the flash rate N_{fl} shown in Figure 5.

The black square in Figure 5 shows typical Earth lightning with an average energy of 10^9 J and a rate of $\sim$3 km^{-2} $year^{-1}$. The latter corresponds to a global rate of 45–50 flashes per second as obtained from satellite measurements (Christian et al., 2003). The dark gray region is the region excluded by Voyager observations which we reproduced from Desch and Kaiser (1990). The light gray region is the region excluded by Cassini observations, which we have just calculated and which of course also comprises the Voyager excluded region. Figure 5 clearly shows that if Titan were producing lightning with a similar energy and cadence as at Earth, the flashes would be easily detected by the very sensitive RPWS instrument. Further, if the lightning at Titan is as energetic as at Earth, but less frequent, its flash rate has to be over a millions times less to slip by undetected by Cassini. A flash rate limit of 10^{-6} km^{-2} $year^{-1}$ means just $\sim$80 flashes per year all over Titan. Conversely, if the flash rate is similar to Earth's rate, the lightning has to be over 5,000 times weaker in energy to go undetected by Cassini.

One can see in Figure 5 that the maximum flash rate decreased by about 2 orders of magnitude from the Voyager to the Cassini excluded region since Cassini performed more than 100 flybys compared to the single Voyager 1 flyby. The maximum flash energy also should decrease at least by a factor of $\sim$20 compared to the Voyager observation since Cassini came closer to Titan and made several flybys with altitudes around 1,000 km compared to the 4,400 km altitude of Voyager 1. However, Figure 5 only shows a decrease by a factor of 5. The reasons for this could be that Desch and Kaiser (1990) overestimated the sensitivity of the Voyager radio receiver and overestimated the power flux of lightning at radio wavelengths. Our result is based on the detection capability of Cassini RPWS for terrestrial lightning as demonstrated during the Earth flyby (Gurnett et al., 2001), and therefore we believe that our estimate of the radio noise for lightning should be correct. The dashed line at 4×10^6 J indicates the factor of 20 between the lightning energy restrictions imposed by Cassini and Voyager 1. This factor is probably even higher since Cassini RPWS was more sensitive than the Voyager radio instrument (Gurnett et al., 2004; Imai et al., 2011). In any case, the new restrictions imposed by the Cassini observations are the ones which are relevant.

We note that for the calculation of lightning search times and rates above we did not take the duty cycle of the instrument into account. The HFR as a frequency sweeping receiver only spent slightly less than half of the time at frequencies above 1 MHz, at which the reception of potential Titan lightning signals unobstructed by SKR is possible. However, since sweeps are regularly taken every 16 s in the most common survey mode, a Titan lightning storm consisting of several tens of flashes within a few hours should have easily been detected despite the limited listening time. On Earth, typical thunderstorms have hundreds of flashes within a few hours (Rakov & Uman, 2003). Furthermore, we also did not subtract the amount of time when the reception of SEDs made the detection of Titan lightning practically impossible, since our calculation of Titan flash rate limits should be understood as an order of magnitude estimation.

5. Discussion and Conclusions

The new restrictions made by Cassini would still allow Titan lightning with the following two different characteristics: There could be Titan lightning with a strength similar to Earth lightning, but which is extremely rare (just tens of bursts per year). Since convective clouds have been seen during several Titan flybys (Griffith et al., 2014) and obviously none of them showed any lightning activity, it is improbable that rare superstorms with lightning activity exist as we have observed Titan with Cassini for more than 13 years. The second kind of potential Titan lightning would be extremely weak discharges, which were not detected by Cassini RPWS. Our new restrictions would allow Titan lightning ~5,000 times weaker than average Earth lightning with energies lower than 2×10^5 J. Such lightning would have currents of the order of hundreds of amperes in contrast to an average terrestrial flash with a current of ~30 kA, which can be estimated from the fact that the lightning energy is proportional to the current squared (Rakov & Uman, 2003). Such lower currents are comparable to a stepped leader process or continuing currents for terrestrial lightning, but they cannot take place without any return stroke. In the early stages of intracloud lightning the leaders also can have currents below 1 kA (Rakov & Uman, 2003). Another possibility not included in our new restrictions is that the lightning radio emissions are damped by ionospheric layers at low altitudes due to high collision frequencies between electrons and neutrals. This is assumed to be the case at Jupiter (Zarka, 1985), where no lightning was observed at a few MHz, but at 600 MHz (Brown et al., 2018). Calculations confirming the transmission of radio waves in the MHz-range through Titan's ionosphere have been done for pre-Cassini ionospheric models (Schwingenschuh et al., 2001), but not with updated Cassini results. However, and in contrast to Jupiter, no optical flash signals have been reported at Titan, so also this possibility is rather unlikely.

The simplest solution is that lightning on Titan does not exist, and this might be due to the following reason: The enhanced electric conductivity in the troposphere of $\sim 10^{-11}$ S m^{-1} (Béghin et al., 2012; Hamelin et al., 2007; Mishra et al., 2014) leads to dissipation currents which are larger than the charging currents. As a consequence large-scale electric fields inside a cloud cannot develop. Tokano et al. (2001) have modeled the charging of particles in Titans clouds by free electrons and derived a temporary maximum of electric fields up to 2×10^6 V m^{-1}. However, they assumed a conductivity of 10^{-13} S m^{-1} at the surface and therefore underestimated the dissipation currents. Additionally, Köhn et al. (2019) have recently shown that the inception of streamers is more difficult in Titan's N_2:CH_4 atmosphere compared to the terrestrial N_2:O_2 atmosphere. According to them a successful streamer inception would require a large electric field of 4.2 MV m^{-1}, which might not be present and is not even reached in the model of Tokano et al. (2001).

The most probable reason for the nondetection of Titan lightning with Cassini RPWS is simply that it does not exist. This is important for the prebiotic chemistry of Titan since several organic compounds (e.g., Borucki et al., 1988; Plankensteiner et al., 2007) may need high temperatures as found in lightning channels to be formed. Furthermore, it might be relevant for the construction of the future rotorcraft Dragonfly, which is planned to be flown in Titan's atmosphere in 2034 at the earliest. It is highly improbable for Dragonfly to be struck by a Titan lightning stroke.

Data Availability Statement

Cassini RPWS data are available through the Planetary Plasma Interactions Node (https://pds-ppi.igpp.ucla.edu/) of NASA's Plantary Data System (PDS). The relevant data set to look for lightning is the calibrated low-rate full-resolution data with the data ID CO-V/E/J/S/SS-RPWS-3-RDR-LRFULL-V1.0 and https://doi.org/10.17189/1519059. The supporting information to this article can be found at this site (https://doi.org/10.5281/zenodo.3947775).

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