The Methane Influence as a Self-polarized Aerosol in Titan's Electrical Activity

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ABSTRACT: Microphysics that generates lightning flashes is associated with the physical chemistry properties of the local occurrence atmosphere. The principal agent of the electrical activity in Titan could be the methane because of its self-polarization properties or pyroelectricity. We calculate the charge obtained by Titan's thunderclouds due to methane, using the approximations of thunderclouds as telluric capacitors. We present a time dependent mechanism because the life time of thunderclouds is very low; for that, we employ common atmospheric approach used for the Earth, because the similitude of both atmospheres in their chemical compositions. In Titan's atmosphere the methane concentration is bigger than the Earth, and the electrical activity is superior, so the observed phenomenology seems to agree with this model.

1. INTRODUCTION

The Methane is an aerosol associated with the terrestrial electrical activity, in one of the most eminent phenomena of atmospheric electric activity in Venezuela, Lightning over the Catatumbo River, where it is possible to observe the presence of lightning without rainfall [Falcon et al., 2001]. Besides, the methane has been considered to be a basic element for the generation of lightning in Titan [Tokano et al., 2001], also is a common component in the atmospheres of the solar system planets that have been identified with or possible carriers of electrical activity; with a composition that varies between 0.02 % (Earth) and 3 % (Titan).

On the other hand, the methane is a self-polarized aerosol or pyroelectric; these pyroelectrics materials have the property of polarizing spontaneously due to the intrinsic symmetries of the molecules that constitute it, that is, whose electrical displacement vector is not null, even without the presence of electrical external fields [Landau and Lifshitz, 1981]. If such materials are dissolute in an atmosphere of any planet, their will be an important agent in the generation of electrical activity, and they could serve to explain the formation of the electrical charges. Due to the low methane dielectric constant (k=1.67), many researches label it as a poor candidate for electrical charging (see Tokano et al., [2002] and reference there in) but the methane influence in lightning generation is not because its dielectric properties, it is for its pyroelectrical properties.

We study Titan because this moon possesses a methane concentration sufficient to demonstrate that methane is the principal causer of the electrical activity, due to its pyroelectrics properties. Besides this celestial body has been the center of attention of many authors that are interested in planetary electrical activity, being able to be this moon, the key for the comprehension of the electric atmospheric activity [Desch et al., 2002].

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2. PYROELECTRIC PROPERTIES OF METHANE

Methane is a mesoscopics aerosols which act in intermediate scales in the convective clouds in Titan, and its ethereal chemistry composition present a dipolar moment electrically auto-induced. Methane has a lattice constant of $2a=1.095$ Å and an angle of $\alpha=109.5°$ that correspond to the orbital *s-p (H-C-H)* in tetrahedral symmetry [Morrinson, 1996], of the symmetry group T_d in Schoflield's notation. It must be considered that the crystalline configuration of the methane belongs to the C_4 symmetry group, these molecules is pyroelectrics, which polarize spontaneously when have been formed crystals lacking of symmetry centers (it excludes certainly the *NaCl* that is a cubic system). The crystals formation of pyroelectrics type in the cloud might create spontaneous dipolar fields, so as that the aerosols crystallize under some types of symmetry; the electrical displacement vector is [Landau and Lifshitz, 1981]:

$$\vec{D} = \vec{D}_0 + \vec{P} + \varepsilon_0 \vec{E} \qquad (1)$$

With P is the polarization and E is the external electric field that in this case is Titan's atmospheric electric field, and ε_0 is the vacuum permittivity constant. Notice that still in absence of an exterior electrical field, there will be a not null electrical displacement that would favor the charges separation and even might originate the avalanche needed in lightning generation models that Rakov and Uman [2003] mention.

To estimate the intrinsic electrical displacement D_0 of methane, we will suppose a cloud of diluted (ideal) gas, in absence of external fields. By the Gauss Law it is obtained that intrinsic electrical displacement is equivalent to the superficial charge density (σ); this can be interpreted as, if in every point of the cell, the field is produced by the most near molecule of methane; despising the contributions of others molecules in conformity with the approximation of ideal gas, it is valid to suppose that $x \sim a$, that is the distance x is in the order of methane lattice constant. On the other hand, in the same approximation $x \sim a$ for the electric field intensity E, in the z-axis, for the methane we obtain:

$$E_{dipole} = -\frac{4}{4\pi\varepsilon_0}\frac{q2a.\cos\alpha}{\left(x^2+a^2\right)^{3/2}} \approx \frac{e\cos\alpha}{\sqrt{2}\,\varepsilon_0 \pi a^2} \qquad (2)$$

With e the electrons charge. Since, as the Gaussian approximation for a cloud is independent, in the classic description, of the volume of the cloud, we have that in the limit case of a monomolecular cloud, both expressions of electric fields must coincide ($E_{dipole} \sim \sigma/\varepsilon_0$), follows that:

$$D_0 = \sigma \approx \frac{e\cos\alpha}{\sqrt{2}\;\pi\;a^2} \approx 6.93\left[\frac{C}{m^2}\right] \qquad (3)$$

Terms into brackets represents the units in international system. If the cloud is uniform, its charge density remains constant, the cloud composition is a fraction ($0 \leq f \leq 1$) of methane, and in this case the intensity of the autoinduced field, in virtue of the realized approximations, finally we obtain for the molecule of methane:

$$E_0 \cong f\,\frac{6.93}{\varepsilon_0}\left[\frac{C}{m^2}\right] = 7.83\,10^{11}\; f\left[\frac{V}{m}\right] \qquad (4)$$

3. TITAN'S CLOUDS INTERNAL ELECTRIC FIELD AND ASSOCIATED CAPACITANCE

The results of Tokano et al. [2001] for internal electric field was $2.5\ 10^6\ V\,m^{-1}$, however, they said that the breakdown field may be slightly smaller than on Earth but by only no more than a factor of 2, and they also said that there is so far no estimate of Titan's fair-weather field (E); so in a firth approach we are going to despise the two last terns of equation (1), here we suppose that the greater contribution to the internal electric field is due to the pyroelectrical properties of methane and not for the external electric field, like in the Earth [Falcon and Quintero, 2007]. Thereby, the internal electric field for Titan's thunderclouds is $E_{int} = 7.05\ 10^{11}\ Vm^{-1}$, using a methane fraction in clouds composition of $f = 0.9$, to not suppose that clouds are entirely of methane.

The thickness of the thunderclouds is *16 Km* [Tokano et al., 2001]; we estimated the associated capacitance using the cloud geometry as a parallel-plane capacitor or the telluric capacitor approach [Iribarne and Cho, 1980]; the associated capacitance obtained is $C = 2.36\ 10^{-7}\ F$, with methane dielectric constant k=1.67.

Also, we can estimated the internal potential difference, using internal electric field and the used thickness of clouds; we obtain $\Delta V_{int} = 1.13\ 10^{16}\ V$, that is a extremely big compared to the breakdown voltage in the Earth [Rakov and Uman, 2003] or the internal electric field obtained with the data of Tokano et al. [2001].

With the associated capacitance and the internal potential difference, we can obtain a cloud maximum charge if the cloud do not discharge, it is $Q_0 = 2.67\ 10^{9}\ C$.

4. TIME DEPENDENT MODEL

It is not possible to do an electrostatic treatment because the charge times are very fast due to the large methane concentration in Titan's clouds, beside this clouds have a very short life time, and they dissipated over the course of two hours, which it is attribute to precipitation [Desch et al., 2002].

Using the telluric approach, we use a simple charge equation for a capacitor in series with a resistance:

$$Q(t) = Q_0(1 - e^{-\frac{t}{RC}}) \qquad (5)$$

Where C is the associated capacitance, Q_0 is the total charge (without discharge), R the resistance of the channel discharge and t is the time. Lightning discharges are about *20 Km* long [Tokano et al., 2001], so to calculated the resistance, we use air conductivity in Titan using figure 1 of Tokano et al. [2001].

We calculate the resistance for Titan cloud-to-ground lightning with a channel length of *20 Km* and a transverse area diameter of *1.6 cm* [Lammer et al., 2001a], that is $R = 1.85\ 10^{11}\ \Omega$. The relaxion time in equation (5) is $\tau = RC = 43660\ s$, it is 12 hours approximately. The results obtained for the charge between 1000-7000 seconds are extremely big (0.1 - 0.4 gigacoulombs). Of course, thunderclouds do not get to that charge, because the cloud is going to discharge when the charge will be as big to reach the breakdown dielectric voltage of Titan's air. In the Earth, thunderclouds charge until 2*0-30 C* approach [Rakov and Uman, 2003], so due to the similitude in both atmospheres, it is logical that in Titan thunderclouds reach that charge too. In Figure 1, we calculated the charge until *60 C*, depending of the frequency.

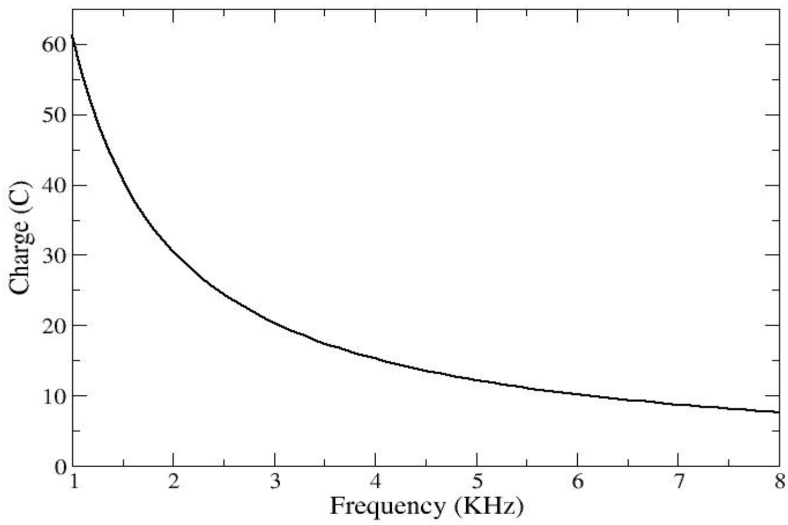

Figure 1. Titan's thunderclouds charge process depending of the frequency.

Lammer et al. [2001b] indicates that cloud-to-ground lightning strokes on Titan would be comparable with so-called type two lightning strokes on Earth, and their maximum energy is at a frequency of about *4 KHz*; this is the same value of frequency is in the frequency range that we obtain.

5. CONCLUSIONS

The charge pyroelectrical model of thunderclouds could be a very certain approach to describe the electrical activity very well because of the fact that in Titan 3 % approach of the atmosphere is methane.

The methane possesses pyroelectrics properties and that could be the hint for the electrical activity in Titan, because methane play similarly role as water in Earth [Desch et al., 2002]. Furthermore, there is confirmed or supposed electrical activity in others planets (see Desch et al. [2002] and references there in), where methane concentration in their atmospheres in considerable.

We estimated the frequency were thundercloud reach its maximum charge before discharge (*2 KHz – 6.25 KHz)*, using a maximum charge similar to the Earth; this result are the same predicted by Lammer et al. [2001b].

Titan atmospheric electricity have been discuses several times showed that certain hydrocarbons can be produced by electric discharges [Tokano et al., 2001]; with this model, we can observe how hydrocarbons could generate lightning discharge, so this can be a self-sustained mechanism that uses nature to regenerate by itself.

The present model for thundercloud electrification in Titan, could be a simplified model, but we want to show that methane pyroelectric properties are important to understand the microphysical mechanism in the charge process of Titan's thunderclouds; the role of the electrical displacement vector in equation (1) is usually ignored, and this could be a serious emission.

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