Constraints on Titan's atmospheric conductivity and buried ocean depth, disclosed by the Schumann resonance

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Abstract

After six years of a thorough data analysis of the data collected by the Permittivity, Wave and Altimetry (PWA/HASI) experiment during the descent of the Huygens Probe through Titan's atmosphere in January 2005, we report the major findings inferred from the measurements of low frequency waves and atmospheric conductivity. The observations display a Schumann resonance trapped within Titan's atmospheric cavity. In this presentation, we describe the characteristics of the observed mode, that allow us to constrain the parameters of the ionospheric cavity and to infer the presence of a conductive water-ammonia ocean buried below the surface, at a likely depth of 70 ± 10 km.

1. Introduction

On Earth, the Schumann resonance is triggered by lightning activity and it was anticipated that a similar observation on Titan would reveal the presence of a reflecting inner surface requisite to sustain such a resonance in addition to a sharp ionospheric boundary. However, given the absence of any acknowledged lightning activity on Titan (Fischer and Gurnett, 2011), we interpret the observed signal at 36 Hz, as the second spherical harmonic of the Titan's cavity, triggered and sustained by intense electric currents induced in the ionosphere through the Saturn's magnetospheric plasma flow.

2. Model and PWA measurements

After ruling out several possible artefacts (Béghin et al., 2009) the observed signal is presently unambiguously interpreted as the second harmonic of a Longitudinal Section Magnetic (LSM_2) mode of atypical Schumann resonance in an inhomogeneous and radially layered cavity. Although the triggering current sources and the ground conductivity are strongly different from conditions encountered for the terrestrial TEM modes, the analytical expression of the modal equation of the eigenmodes can be written in a similar way, as a function of a small number of cavity parameters, such as

$$\omega_l = \frac{c}{a}\left[l(l+1) \frac{h_1 + z_C / \mathrm{Re}\,\varepsilon_c}{h_1 + z_c + \zeta \ln(1/4k^2\zeta^2)} \right]^{1/2} \quad (1)$$

$$\mathrm{Q} = \left[\frac{2 z_C \delta / \mathrm{Re}\,\varepsilon_c + \pi\zeta/2}{h_1 + z_C/\mathrm{Re}\,\varepsilon_c} + \frac{\pi\zeta/2}{h_1 + z_c + \zeta \ln(1/4k^2\zeta^2)} \right]^{-1} \quad (2)$$

where ω_l is the eigenfrequency for the harmonic l (here l = 2), Q is the quality factor, c and k are the free-space light velocity and the wave vector, respectively, a is the Titan's radius (2575 km), h_1 is the altitude of the ionospheric conduction boundary, z_c and ε_c are the subsurface crust thickness and permittivity, respectively, δ is the loss tangent of the crust material, and ζ is the scale height of ionospheric conductivity.

As on Earth, the altitude of the conduction boundary h_1 is nearly the region of maximum signal strength (Fig. 1), i.e. between 90-100 km here, so that we may keep only four unknown parameters (z_c , ε_c, δ and ζ) to be cross-constrained by the measured quantities ω_l and Q. The most likely cross-constraint area for the three parameters of the crust is shown in Fig. 2. The value of the ice thickness determined by the present study strongly suggests that the ice crust lies over an ammonia-rich ocean, which is consistent with either convection or conduction processes. We find indeed that a crust thicker than 80 km would be unstable to convection processes unless the viscosity at the base of the crust would be larger than 2.10^{16} Pa.s, which suggests a temperature less than 220 K. On the other hand, a convective 40-km thick crust cannot be in equilibrium with the internal heating, which suggests a crust growing at the expense of the ocean.

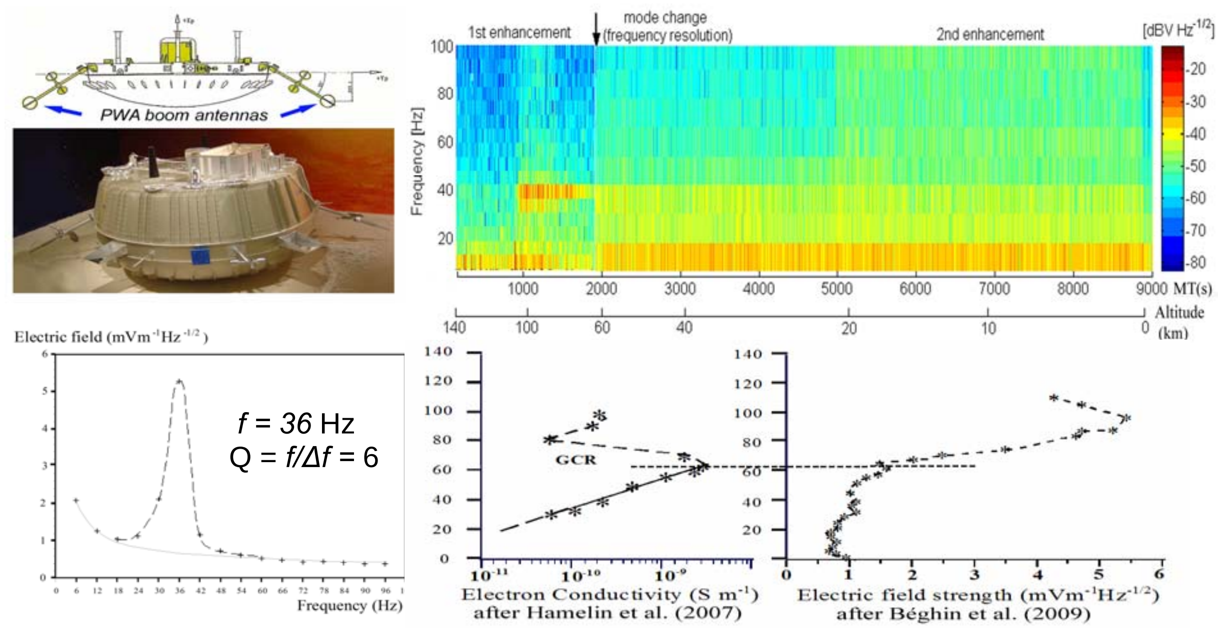

Figure 1. Experimental data. ELF Electric Field and Electron Conductivity were measured with sensors mounted on two deployable booms. A 36 Hz resonance with a level of few mVm^{-1}Hz$^{-1/2}$ and a high Quality Factor (Q = 6) was clearly identified throughout the descent. A peak of conductivity, attributed to Galactic Cosmic Rays, was observed at around 60 km.

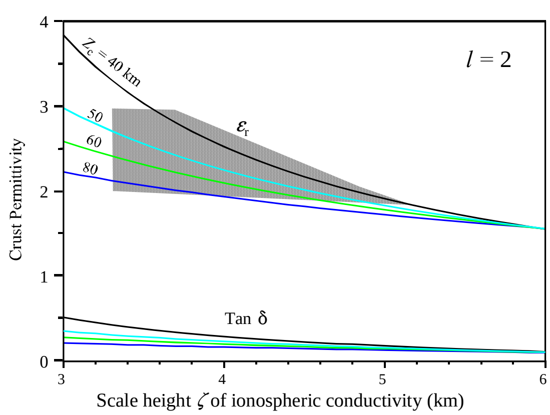

Figure 2. Cross-constrained shadowed area for the ocean depth versus the crust permittivity (2 < Re ε_c < 3) and the ionospheric scale height of conductivity (3.2 < ζ < 5).

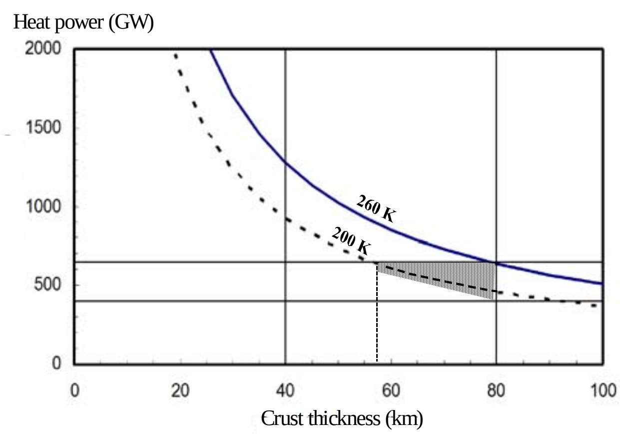

Figure 3. Heat power in equilibrium with the crust thickness (60 < z_c < 80 km) for a temperature of the crust-ocean interface < 260 K.

3. Summary

Our interpretation of the Titan's Schumann resonance complies with a conduction ionospheric boundary lying at ~ 100 km, and a 60 km thermally conductive crust with an ocean temperature of 200 K (Fig.3) or an 80 km convective crust with a minimum viscosity of 5x10^{15} Pa.s.

References

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