Titan ionospheric's cavity as explored by the PWA-HASI instrument on Huygens
(review of results 2005-2011)
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Plan

- Cassini-Huygens and the PWA-HASI instruments
- Electron conductivity and density profiles:
  - the GCR layer
  - RP plateaus: aerosol layers?
- The Schumann resonance(s) and the detection of a buried ocean
- Summary and references

Main contributions from the following institutes:

HASI: Huygens Atmospheric Structure Instrument, CISAS, Padova (I)
PWA: Permittivity, Waves and Altimetry
- IAA: Instituto de Astrofísica de Andalucia, Granada (E)
- IWF: Institut für Weltraumforchung, Graz (A)
- LPCE: Laboratoire de Physique et Chimie de l’Environnement, Orléans (F)
- RSSD-ESTEC, Noordwijk (NL)
Titan exploration with PWA-HASI on Huygens
(PWA: Permittivity, Waves and Altimetry)

Landing on Titan: January 15th, 2005

PWA boom opening: 142 km
Large to small parachute: 114 km

Two telemetry channels to Cassini
But only one transmitted to Earth

First results:
Fulchignoni et al., 2005
Grard et al., 2006

NASA-ESA-ASI mission CASSINI-HUYGENS
The PWA-HASI instrument on HUYGENS
The MI and RP – PWA instruments

Mutual Impedance (MI)
Relative permittivity and conductivity:
\[ \varepsilon = \frac{A}{A_0} \cos(\phi - \phi_0) \]
\[ \sigma = \frac{A}{A_0} \omega \varepsilon \sin(\phi - \phi_0) \]
In a collisional plasma:
\[ \varepsilon \approx 1 \]

Relaxation Probe (RP)

+ ELF – VLF electric field measurements in passive mode.

Titan's ionospheric cavity - M-S3 symposium, Moscow, 10-10-2011
MI results: electron conductivity and density profiles

Velocity effects shall be taken into account:

- experimental data: measured mutual impedance (normalized to vacuum value)
- abacus: computed from models of electronics, sensor geometry and medium models + probe velocity in the medium.

→ electron conductivity

For altitudes > 114 km, MI data are not consistent: one boom is likely not fully opened.

See: Hamelin et al., 2007
RP results: polar conductivity and density profiles

For initial positive or negative charging of the electrode, the potential decay leads to polar conductivities.

Space charge effects shall be taken into account.

Accurate measurements of positive ions conductivity have been lost (in channel A).

The profiles for negative charges are in fairly good agreement with the MI measurements. At altitudes higher than 115 km the MI data have been ruled out.

López-Moreno et al., 2008
Molina-Cuberos et al., 2010

Titan's ionospheric cavity - M-S3 symposium, Moscow, 10-10-2011
The ionized Titan atmosphere as seen by PWA
PWA measurements & theoretical models

Models: MC: Molina Cuberos; BW: Borucki & Whitten

Deviation between models and measurements above ~75 km. Are electrons captured by aerosols?

López-Moreno et al., 2008
Discontinuities revealed by RP: the plateaus
Clues of aerosol layers?

The plateaus are caused by the absence of electrons. Then the Huygens probe is crossing domains, bubbles or layers, without electrons. This could be caused by capture of electrons by aerosols.

The altitude of plateaus:
57.76 ± 0.07 km
71.9 ± 0.3 km
99.7 ± 1.3 km

López-Moreno et al., 2008
ELF Electromagnetic waves in Titan’s ionospheric cavity. Schumann resonance(s).

On board 1024 points DFT analysis in 0-1.5 kHz bandwidth, but only 32 amplitude lines (0-96 Hz) are sent in telemetry,...
But only 16 (6-96 Hz) were received on Earth.

Only one strong emission is observed around 36 Hz (near 2\textsuperscript{nd} Schumann resonance), during all the descent. (after small parachute opening)

Not an artefact!
- Boom vibrations tests at cryogenic temperature show lower frequency mechanical resonance
- Other mechanical interactions studied and discarded
- Modulation at twice the probe rotation frequency

Béghin et al., 2007

Note: the data from the VLF channel (0-10 kHz) allowed to check that no higher frequency emissions might produce aliasing effects in the ELF spectra (3.5 kHz analog filter cutoff frequency).
What particular Schumann resonance on Titan? First approach

- No observed lightning activity and no multiple resonances as on Earth.
- Large power flux of the '36 Hz' ~6 x 10^{-8} W m^{-2} Hz^{-1} that rules out lightning as the source of energy.

- Source of energy likely due to the interaction of Titan with the Saturn co-rotating magnetosphere: induced electric field ~1 mV m^{-1}.
- Excitation of Titan's resonant cavity in high latitude regions.
- Waves are mostly trapped between upper ionosphere and the 60 km peak revealed by PWA.

Simões et al., 2007

Left: Conductivity model. Right: Map of the electric field amplitude (arbitrary normalized units) received from an isotropic EM source located at 200 km altitude, versus frequency, as a function of angular distance, at the altitude of 100 km. Underground reflecting plane at 100 km depth. **Second harmonic near 36 Hz dominates for angular distance around ~80 °**.
Titan's quaint Schumann resonances and ELF underground sounding

Observation facts

- Quasi monochromatic 36 Hz émission with high quality factor ~6
- E mostly horizontal
- Non circular polarization
- 3 sections of linear amplitude profiles linked with conductivity
- Non zero amplitude at the (non conductive) surface (~0.5 mV/m)
- Underground conductive reflector (buried ocean).

- TE mode instead of TM for terrestrial Schumann resonances (triggered by horizontal zonal currents instead of vertical lightning currents)

- Observations compatible with 2$^\text{nd}$ zonal TE harmonic

Béghin et al., 2007 & Béghin et al., 2010
Titan's quaint Schumann resonances and ELF underground sounding Interaction Titan – Saturn Magnetospheric plasma

**Generation mechanism: Ion acoustic instability**
Condition: ion-electron velocity >> ion acoustic velocity
Fulfilled in Titan's ionosphere above ~200 km

**Power Budget**
Max wave power flux density: \(~10^{-7}\) W m\(^2\) Hz\(^{-1}\)
Needed 36 Hz power density: \(~10^4\) W Hz\(^{-1}\)
EM power source (1 kHz bandwidth): \(~10^7\) W
Ionospheric currents amplitude: \(~10^5\) A
Ionospheric potential drop: \(~5\) kV
Total available power: \(~5\) GW
Needed efficiency conversion mechanism: 2%

Béghin et al., 2010

Sketch of the Titan-Saturn magnetospheric interaction. An electrodynamical electric field (\(~1\) mV/m) is induced in the conducting ionosphere of Titan by high velocity (\(~100\) km s\(^{-1}\)) co-rotating Kronian magnetized plasma. A high voltage potential drop (\(~5\) kV) develops between the two opposite hemispheres along Titan-Saturn axis. Induced currents are blown off along the tail in the wake direction along magnetic lines initially draped around the ram hemisphere. Within the ionosphere, the current is thought to generate turbulence through ion-acoustic instability mechanism yielding a quasi-polar vertical ELF magnetic dipole.
Confrontation with models of Titan’s interior

A first estimation on the basis of the electromagnetic waves data and conductivity profile led to a depth of $45 \pm 15$ km of a buried ocean. Confrontation with models of Titan’s interior brings additional constraints for discussing buried ocean depth.

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**Fig. 2.** Cross-constrained shadowed area for the ocean depth versus the crust permittivity and the ionospheric scale height of conductivity. The shadowed area is for most likely values of crust permittivity ($2 < \varepsilon \leq 3$).

**Fig. 3.** Heat power in equilibrium with the crust thickness for two values of temperature at the crust-ocean interface. The two horizontal lines represent mid-member values of the internal radioactive power.

Experimental data $f = 36$ Hz, $l = 2$ (most likely), $Q = 6$, $h_i \sim 100$ km
Thus, the modal equations cross-constrain 4 cavity parameters only:

- Thickness of the Icy Crust $Z_c$
- Permittivity of the Crust $\varepsilon_c$
- Loss tangent of the Crust $\delta \ll \varepsilon_c$
- Mean Ionospheric Scale Height $\zeta$

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- Crust thickness $40 < Z_c < 55$ km implies thermal conduction and NH$_3$ rich water ocean
- Crust thickness $55 < Z_c < 80$ km implies convection transfer with viscosity $> 8 \times 10^{15}$ Pa s
- On both cases the melting temperature at the interface crust/ocean is $160 < T < 260$ K
- Thermal conduction alone ($Z_c \ll 55$ km) implies a crust not thermally stabilized
- Most likely $60 < Z_c < 80$ km, conductive-convective icy crust and NH$_3$ moderate ocean
- Electron conductivity profile: $h_i \sim 100$ km (2 nS m$^{-1}$) and $3.3 < \zeta < 5.1$ km

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Béghin et al., 2011
Results

- A well defined CGR electron layer detected by 2 concurrent techniques.
- Electron layers or bubbles that could be caused by aerosol attachment.
- Schumann resonance generated by the interaction of Titan with the magnetosphere of Saturn.
- Estimation of the depth of the buried ocean from both electromagnetic wave data and Titan’s interior constraints.
- Work in progress: surface permittivity measurements.

Thanks to all european space agencies and NASA. Thanks also to ISSI, Bern for supporting fruitful workshops.
Main papers

Before landing:

After landing:
- C. Béghin et al., 2007, A Schumann-like resonance on Titan driven by Saturn's magnetosphere possibly revealed by the Huygens probe, Icarus 191, 251-266.
- C. Béghin et al., 2009, Titan's native ocean revealed beneath some 45 km of ice by a Schumann-like resonance, C.R. Geoscience, doi:10.1016/j.crte.2010.03.003.