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Composition Homogeneity of 67P as seen by CONSERT

Alain Herique (1), Wlodek Kofman (1,2), Sonia Zine (1), Jürgen Blum (3), Jean-Baptiste Vincent (4), Valerie Ciarletti (5)

(1) Univ. Grenoble Alpes, CNRS, CNES, IPAG, 38000 Grenoble, France, alain.herique@univ-grenoble-alpes.fr
(2) Space Research Centre, PAN, Warsaw, Poland
(3) Institut für Geophysik und extraterrestrische Physik, TU Braunschweig, Germany
(4) DLR Institute of Planetary Research, Berlin, Germany
(5) LATMOS/IPSL, UVSQ, UPMC, CNRS, Guyancourt, France

Abstract

CONSERT fathomed the interior of comet 67P measuring wave propagation between ROSETTA and PHILAE. The measured signals indicate no heterogeneities at metric scale. The goal of this paper is to interpret this result in terms of composition, porosity and local dust-to-ice ratio and to analyze these constraints in terms of accretion scenarios.

1. CONSERT measurements

During the first night after the landing of Philae, CONSERT [1] operated during 9 hours and acquired measurements through the small lobe (head) of comet 67P/ C-G. The analyses and interpretation have been done using the shape of the received signals and then 3D modeling of the signal propagation through the comet [2].

The first analyses concerned the propagation delay from which the average permittivity of the cometary interior was derived. This was done using a 3D model of wave propagation through the comet. Dielectric data for ices and dusts, compared with CONSERT measurements, constrain the possible constituents of comet 67P/CG [2], [3]. The measured propagation delay permitted to derive the dielectric properties of the interior [2]. The inferred real part of permittivity is ε=1.27, which is very low (permittivity of vacuum is 1, of water ice about 3.1 and of dust constituents even higher). Thus, the interior of the comet is very porous.

The second analyses concerned the internal structure. The shape of the signal is very close to the shape of calibration signals and shows no detection of scattering by inhomogeneities in the medium. This indicates that the interior is homogenous at the scale of a few wavelengths (1 wavelength is about 3.3m in vacuum) [2]. This conclusion lead to the study of the sensitivity of CONSERT to detect the inhomogeneities in order to constrain the internal structures in terms of size and composition at a scale commensurate with the wavelength [4]. The measurements of the experimental pulse width were compared with the 3D simulation in the non-homogenous medium with fractal- and sphere-based structures. Comparison with width values gave constraints on the structures inside the nucleus that would be compatible with CONSERT data. It was shown that CONSERT observations cannot exclude or give constraints on any scale lower than 1 meter. The presence of 3-m-scale structures is compatible with CONSERT measurements provided that the permittivity contrast of these structures is less than 0.25.

2. Bulk composition and porosity

In [3], compositional analyses were developed to interpret the bulk permittivity using a large database of organic materials from the literature and from laboratory measurements. Since many materials have similar permittivity values in CONSERT frequency range, using permittivity does not discriminate materials directly, but allows excluding some. To this end, one tests different composition models of the nucleus corresponding to cosmochemical end members of 67P/CG dust. They include pure silicate dust and its mixture with an increasing content of a carbonaceous material (comprising both insoluble and soluble species).

The conclusion drawn was that an important fraction of carbonaceous material is required in the dust in order to match CONSERT permittivity observations. The minimum required content of the carbonaceous material is 75% vol. (66% mass fraction). This suggests that comets represent a massive carbon reservoir. Thus, the nucleus of the comet must be very porous (72-87%), with 6-12% ice and 16-21% refractory (dust) by volume [3] and the refractory to ice ratio is larger than 3 [5].

3. Variability of the composition

In the same way, the limit of heterogeneity previously estimated at $\Delta\varepsilon$=0.25 is now analyzed in terms of possible local deviations from the average composition and porosity [6]. For example, assuming a low-density medium with higher density inclusions such as boulders, we have shown that for 3m-sized blocks, the permittivity contrast must remain below 0.25 to be compatible with CONSERT measurements: which constraints does this limit put on the variability of composition or porosity? To answer this question, we study the effects of a local variation of the composition, removing any global constraint on density, D/I and permittivity. Local variations of permittivity of any subscale inclusions is possible as long as they do not lead to ε varying of more than $\Delta\varepsilon$=0.25 around the CONSERT average value ε=1.27. We tested two scenarios to understand this result [6]:

The first scenario considers a local variation of the density assuming a constant composition of the constitutive material everywhere in the nucleus: constant D/I ratio and constant composition of the ice fraction and of the refractory material. In this scenario, the porosity variation must remain within the range 65-85% to fit CONSERT observations.

The second scenario consists in a local variation of the dust/ice ratio considering constant porosity and constant composition of each fraction. With this scenario, CONSERT is not able to detect such local variations, even if they range from pure porous ice to dry porous dust. This lack of sensitivity was expected considering the very low permittivity contrast between the modeled ice and dust fractions (respectively 2.7 and 2.6)

Some alternative scenarios have been studied such as a variation of the volatile versus porosity at constant dust fraction, the variation of the ice fraction composition from pure CO or CO2 ice to pure water ice or variation of the dust fraction composition from pure organics to 70% silicates. The porosity remains the main driver for these alternative scenarios and the sensitivity to other parameters remains limited [6].

4. Conclusion and discussion

CONSERT is not sensitive to any heterogeneity with dimensions of one meter or lower. At scales larger than a few meters (typically 3m) the local variation of porosity has to be lower than ±10 percent points (total range from 65% porosity to 85%) and no significant constrains can be established on the local variations of other physical quantities.

This result gives an additional constraint on comet accretion scenarios, which have to generate porosity heterogeneities at scales lower than one meter, or with low amplitude variations for larger scales.

As developed in [3], CONSERT-derived constraints on heterogeneity are compliant with the scenario of gentle gravitational collapse of a “pebble” cloud [7], including possible re-accumulation after a catastrophic collision. It is not compliant with the hierarchical collisional growth scenario, where the “pebbles” continue to grow beyond the bouncing barrier [8].

This result consolidates also the non-primordial interpretation of "goosebumps", circular pattern optically observed on 67 P surface [9].

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