Waves and Plasma observed in the Earth's Plasmasphere by the MIP Mutual Impedance Probe Onboard ROSETTA

Jean-Gabriel Trotignon[1], ***Xavier Vallières***[1], ***Dominique Lagoutte***[1], ***Jean-Pierre Lebreton***[2]

[1]Laboratoire de Physique et Chimie de l'Environnement, Centre National de la Recherche Scientifique, Orléans University, 3A, Avenue de la Recherche Scientifique, F-45071 Orléans cedex 02, France,
Jean-Gabriel.Trotignon@cnrs-orleans.fr, Xavier.Vallieres@cnrs-orleans.fr, Dominique.Lagoutte@cnrs-orleans.fr

[2]Solar System Division, ESA/ESTEC, NL-2200 AG Noordwijk, The Netherlands
Jean-Pierre.Lebreton@esa.int

Abstract

ROSETTA will rendez-vous with comet 67P/Churyumov-Gerasimenko round 2014 and study it for a period of nearly two years. The Mutual Impedance Probe, MIP, onboard the ROSETTA orbiter, has to measure the electron density and temperature in the cometary coma, and in particular, inside the contact surface. Furthermore, MIP will determine the spectral distribution of natural waves from 7 kHz to 3.5 MHz. To reach the comet, the spacecraft must undergo four planet gravity assistances. During the first two Earth fly-bys, which occurred in March 2005 and November 2007, valuable observations have actually been made by the MIP in the Earth's plasmasphere, a high electron-density region dominated by the Earth's magnetic field. The MIP principle of measurement and the instrument design are first briefly recalled, and then the scientific results obtained in the Earth's plasmasphere are presented.

1. Introduction

ESA's comet chaser, ROSETTA comprises an orbiter and a small lander, Philae [1]. Each of these carries a large complement of scientific experiments to study comet 67P/Churyumov-Gerasimenko from August 2014 to the end of 2015. The ROSETTA mission will therefore allow plasma physicists to investigate for the first time the innermost regions of the coma, and in particular the region inside the contact surface that was only skimmed by Giotto. This boundary prevents the inner part of the coma being reached by the interplanetary magnetic field, perturbed by the presence of the extremely large cometary environment. ROSETTA was launched as flight 158 on 2 March 2004 by an Ariane-5G rocket from Kourou, in French Guiana. To leave the inner Solar System behind and set course for the distant comet at about 5.25 AU, ROSETTA has to receive gravity assists three times from Earth (in March 2005, November 2007, and November 2009) and once from Mars (in February 2007). The Mutual Impedance Probe, MIP, part of the Rosetta Plasma Consortium, RPC [2, 3], will measure the aeronomical parameters, electron density and temperature, as well as plasma flow velocity in the inner coma. In addition, it will investigate natural waves in the 7 kHz to 3.5 MHz frequency range and monitor the dust and gas activity of the nucleus. The purpose of this paper is to present the MIP experiment in context and mostly to show the observations made in the Earth's plasmasphere during the first two Earth swingbys.

2. The Mutual Impedance Probe, MIP

The MIP instrument comprises a lightweight electrical sensor made of carbon fibre and an electronics board [4]. The latter is for experiment managing, input/output data handling, and signal processing in the 7 kHz-3.5 MHz range. The comb-shape sensor unit consists of two receiving and two transmitting electrodes supported by a 1-m long cylindrical bar. The receiving electrodes are at the ends of the bar in order to maximise the effective length of the antenna for natural wave measurements (in passive mode, when no signals are transmitted). The electrodes are small metallic cylinders mounted at stud tips.

The MIP principle of measurement consists in determining the mutual impedance between a transmitting Hertz dipole and a receiving one. The transmitting electrodes are excited from a constant current source, at given frequencies lying in a range that includes the plasma frequency Fpe ($Fpe = 9\sqrt{Ne}$, where Fpe is expressed in kHz and the electron density Ne in cm^{-3}), while the receiving electrodes are connected to a voltmeter with very high input impedance. Both the imaginary and real parts of the mutual impedance $Z = V/I$ depend on dielectric properties of the plasma in which the electrodes are immersed. Moments of the thermal electron distribution function, such as the density, temperature, and drift velocity may therefore be deduced from the frequency response (also called transfer impedance or mutual impedance) of the MIP.

Whenever the magnetic field is low, i.e. the electron cyclotron frequency Fce ($Fce = 28\,B$, where B is expressed in nT and Fce in Hz) is much lower than Fpe, the frequency response exhibits one resonance peak near Fpe, from which the total plasma density Ne is derived, and an interference pattern associated with the propagation of thermal waves which gives the plasma Debye length λ_D. This interference pattern, which results from the beat of standing and propagating signals generated by the transmitting electrodes, is sensitive to Doppler effects, the electron drift velocity may thus be determined.

In addition, since λ_D is a function of both Ne and the thermal electron temperature Te, a direct measurement of Te becomes possible ($\lambda_D = 6.9\,(Te/Ne)^{1/2}$, where λ_D is expressed in cm, Te in °K, and Ne in cm^{-3}). Conversely, if Fce and Fpe are of the same order of magnitude, resonances at the upper-hybrid frequency Fuh ($Fuh = (Fpe^2 + Fce^2)^{1/2}$) and Bernstein frequencies FQn, and anti-resonances at Fce and harmonics $nFce$ are currently observed. In the latter case, the magnetic field strength may therefore be deduced.

3. MIP Measurements in the Earth's Plasmasphere

MIP and the 4 other instruments of RPC were switched on during the first two Earth swingbys, in early March 2005 and mid-November 2007 (Fig. 1). Calibration and general testing were the main objectives, nevertheless valuable observations of the Earth's space environment have actually been made, in particular by the MIP [5], in the plasmasphere, the cold and high electron-density region dominated by the Earth's magnetic field.

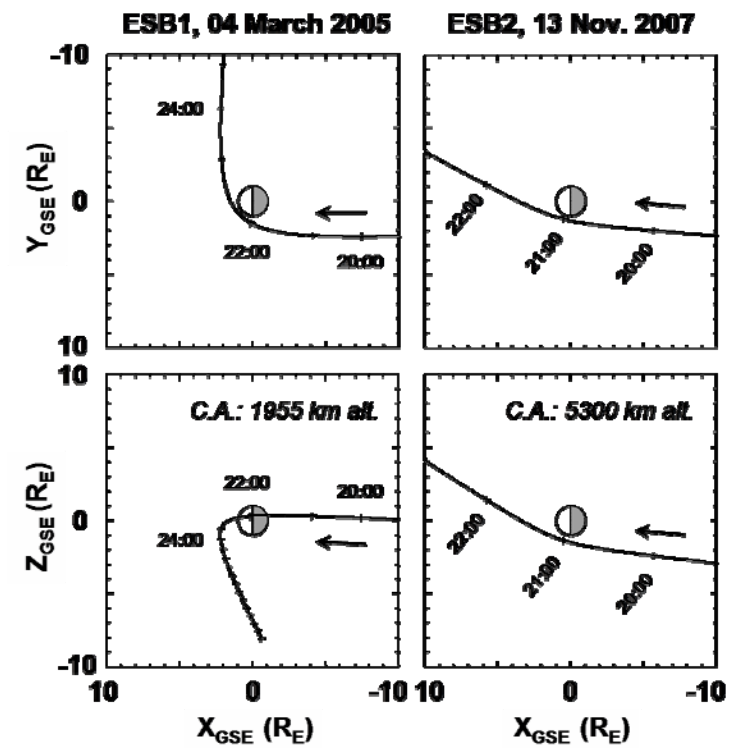

Fig. 1. Rosetta trajectories in geocentric solar ecliptic (GSE) coordinates during Earth swingbys 1 and 2. It is worth noting that Rosetta went farther from the Earth's surface in 2007 (5,300 km altitude) than in 2005 (1955 km).

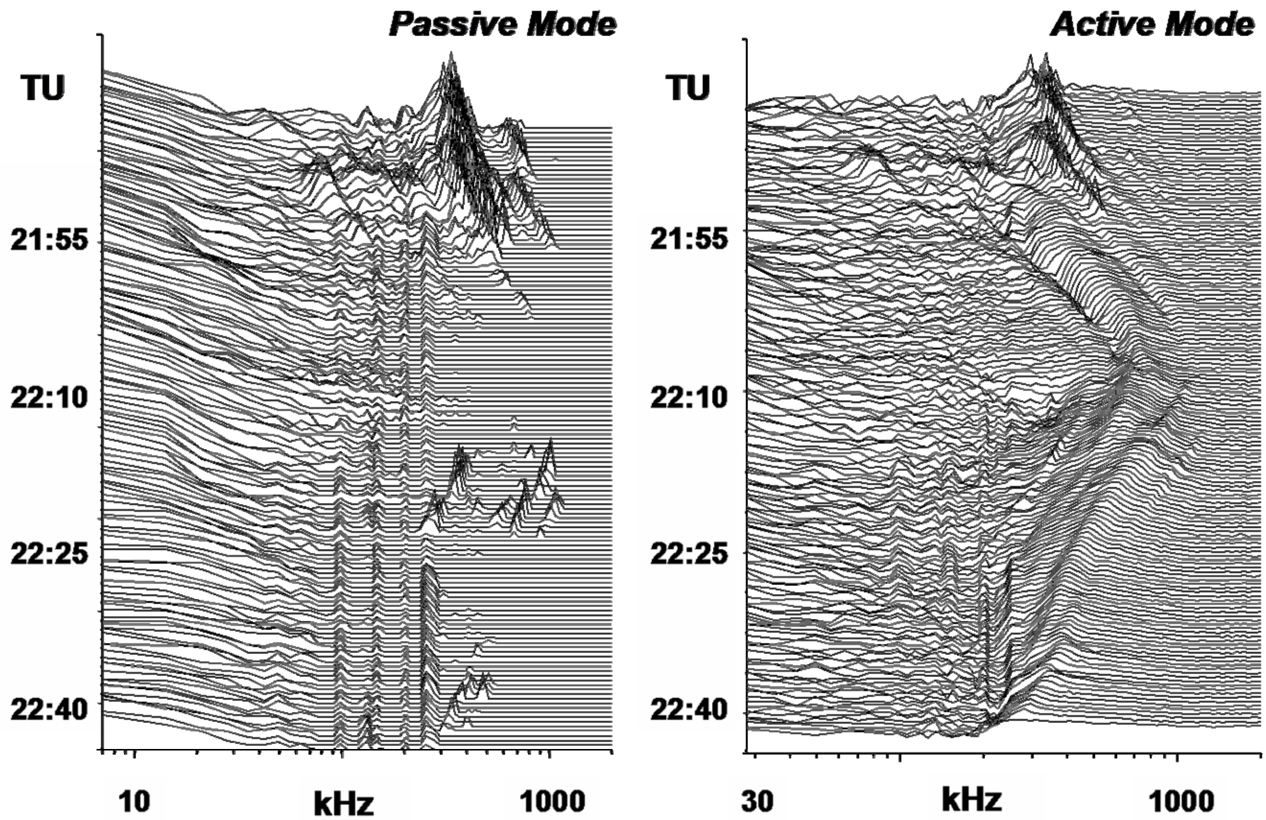

Fig. 2. 20-s average passive (left panel) and active (right panel) spectra recorded by the ROSETTA/RPC/MIP instrument during the first Earth flyby on 4 March 2005. The left panel shows kilometric continuum radiations round 21:45, 22:15, and 22:35 UT, at about 40, 12, and -24° magnetic latitude. The low frequency vertical structures seen on both panels are instrument interferences. The other structures in the right panel are the signatures of characteristic plasma frequencies (plasma frequency *Fpe*, upper hybrid frequency *Fuh*, and Bernstein's frequencies *FQn*) in the mutual impedance modulus.

Passive and active impedance measurements made on 4 March 2005 are respectively shown on the left- and right-hand sides of Fig. 2. The time is running from top to bottom, between 2140 UT and 22:40 UT and each spectrum is an average of five consecutive spectra, each of 4-s duration. During this one-hour period, ROSETTA moved from the nightside to the dayside of the Earth's plasmasphere at geocentric distances between 1.3 R_E, at closest approach, and 2.5 R_E, at extremities. Let us also note that a quite large magnetic latitude interval was covered, from 36.1° to -28.2°, and the magnetic equator was crossed a little bit after 22:20 UT, around which the most intense values of the antenna impedance modulus were actually registered. The narrow-banded and very intense structures extending from 250 kHz to over 600 kHz are kilometric continuum radiations, they are seen on both the passive and active plots, from the beginning of the plots to 21:53 UT. These emissions have currently been observed, in particular by Geotail as fine structures of narrow-bandwidth linear features that slowly drift in frequency, in the 100 kHz to 800 kHz frequency range, i.e. almost in the same range as auroral kilometric radiations [6, 7]. A distinctive feature of the waves observed onboard ROSETTA, is that we are here in the evening sector at 18-21 magnetic local time and quite far from the magnetic equator, at 30-40° magnetic latitude.

4. Conclusion

After a commissioning period of a few months after the 2 March 2004 launch from Kourou, the MIP experiment has been declared fully operational. Furthermore, valuable scientific measurements were made during the first two Earth gravity assists, it was in the Earth's plasmasphere on 4 March 2005 and 13 November 2007. Both the magnetic field strength and the total plasma density have been measured and compared with models. The Debye length determination, and hence the temperature determination, will require additional efforts in cooperation with the LAP Langmuir probe experimenters. Only a crude estimate may indeed be made in the absence of a reliable modelling of strongly magnetized plasmas, which is fortunately not the case of a comet ionized environment. Finally, very intense kilometric continuum radiations were observed, they are located at unusual magnetic latitudes.

7. References

1. J. Ellwood, G. Schwehm, the ROSETTA Project Team and P. Bond, Rosetta's new target awaits, *ESA bulletin* **117**, 2004, pp. 5-13 .

2. J. G. Trotignon, R. Boström, J. L. Burch, K.-H. Glassmeier, R. Lundin, O. Norberg, A. Balogh, K. Szegö, G. Musmann, A. Coates, L. Åhlén, C. Carr, A. Eriksson, W. Gibson, F. Kuhnke, K. Lundin, J. L. Michau, S. Szalai, The Rosetta Plasma Consortium: technical realization and scientific aims, *Adv. Space Res.* **24**(9), 1999, pp. 1149-1158 .

3. C. Carr, E. Cupido, C. G. Y. Lee, A. Balogh, T. Beek, J. L. Burch, C. N. Dunford, A. I. Eriksson, R. Gill, K. H. Glassmeier, R. Goldstein, D. Lagoutte, R. Lundin, K. Lundin, B. Lybekk, J. L. Michau, G. Musmann, H. Nilsson, C. Pollock, I. Richter, J. G. Trotignon, RPC: the Rosetta Plasma Consortium, *Space Sci. Rev.*, doi: 10.1007/s11214-006-9136-4, **128**, 2007, pp. 629-647 (2007).

4. J. G. Trotignon, J. L. Michau, D. Lagoutte, M. Chabassière, G. Chalumeau, F. Colin, P. M. E. Décréau, J. Geiswiller, P. Gille, R. Grard, T. Hachemi, M. Hamelin, A. Eriksson, H. Laakso, J. P. Lebreton, C. Mazelle, O. Randriamboarison, W. Schmidt, A. Smit, U. Telljohann, P. Zamora, RPC-MIP: the Mutual Impedance Probe of the Rosetta Plasma Consortium, *Space Sci. Rev.*, doi: 10.1007/s11214-006-9005-1, **128**, 2007, pp. 713-728.

5. J. G. Trotignon, X. Vallières, D. Lagoutte, S. Grimald, J. P. Lebreton, P. Robert, The MIP experiment of the Rosetta orbiter: a mutual impedance probe for waves and plasmas diagnosis, in *Advances in Geosciences,* eds. A. Bhardwaj et al., Planetary Science, World Scientific, Singapore, 2008, in press.

6. K. Hashimoto, W. Calvert, H. Matsumoto, Kilometric continuum detected by Geotail, *J. Geophys. Res.* **104**, 1999, pp. 28,645-28,656.

7. J. D. Menietti, R. R. Anderson, J. S. Pickett, D.A. Gurnett, H. Matsumoto, Near-source and remote observations of kilometric continuum radiation from multispacecraft observations, *J. Geophys. Res.* **108**(A11), doi: 10.1029/2003JA009826, 2003, pp. 1393-1404.