INFLUENCE OF ELECTRIC CHARGING ON THE ROSINA INSTRUMENT IN THE PLASMA ENVIRONMENT OF COMET 46P/WIRTANEN

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1. Abstract

The **Rosetta Mission** was approved as a Cornerstone Mission in the ESA long-term space science program. The Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (**ROSINA**) is designed to determine the elemental, isotopic and molecular composition of the atmosphere and ionosphere of comets. The spacecraft will rendezvous with comet 46P/Wirtanen and will remain in its orbit for two years. The **plasma environment** of 46P/Wirtanen mostly leads to **positive spacecraft charging**. The resulting electric field spreads around Rosetta and influences the ion trajectories. Consequently, the ion spectra and ion densities measured on board the spacecraft are affected. In order to favour ion detection, attraction grids are mounted in front of the sensor inlets of ROSINA.

The **particle-in-cell code** PIComet is being developed to make predictions of the expected ion measurements. The necessary potential bias of the attraction grids can be derived from the simulations. Also the detectable energy and angular ranges can be estimated.

2. Motivation

The goal of the international ESA-mission Rosetta is to rendezvous with comet 46 P/Wirtanen and to study the nucleus and its environment for a period of nearly two years. Rosetta is expected to provide a vital insight into the origins of the solar system. The spacecraft will be launched in January 2003. On its eight-year journey to the comet, the spacecraft will pass close to two asteroids (Otawara and Siwa). The near-nucleus phase starts at a heliocentric distance of about 3.25 AU.

The ROSINA instrument [1] is designed for the in situ investigation of elemental, isotopic and molecular gas fluxes from comets. ROSINA consists of three sensors, COPS (COmet Pressure Sensor), DFMS (Double Focusing Mass Spectrometer) and RTOF (Reflectron Time of Flight Mass Spectrometer). DFMS and RTOF detect ions and neutral particles. The measurements in ion-mode are strongly affected by spacecraft charging effects.

The field of in situ mass spectrometry for space research demands estimations of the possible data yield before a mission is launched. Measuring cold ions under spacecraft charging conditions is a particularly delicate matter. In the presence of electric and magnetic fields, ion detection is mass selective and the obtained mass spectra can be distorted. Numerical simulation, based on data of the expected space environment, should therefore include the electric potential distribution and the magnetic field near the sensor, as well as the resulting particle trajectories.

There is a variety of simulation codes for spacecraft charging and ion optics. Most of them particularly match the conditions of Earth orbits. Others are non-commercial or hardly available due to export restrictions. Programs for ion optics in turn do not take into account space charge as it is typical for plasmas. At last, one cannot be sure of the physical validity of any non-open source code. In order to have a reliable tool, a code for plasma simulation is being developed [2].

3. Plasma Environment

Two scenarios concerning the characteristics of the plasma environment of 46P/Wirtanen must be distinguished, which are sketched in the first two Figures.

In one case, the spacecraft is located outside the cometary contact surface (Figure 1). The ecliptic is the x-y plane. On the top panel, the magnetic field **B** is perpendicular to the ecliptic. The entire particle motion is parallel to the x-y plane. In the lower panel, the vertical section (x-z-plane) for an arbitrary **B** is shown. Under these conditions there is one optimum moment for ion detection per orbit when $v_{ion} = 0$ in the spacecraft frame. However, the ion yield can still be zero because it is determined by the orbital elements of the spacecraft, namely by the inclination and the ascending node.

The 20°-cone in the wake of the comet will be avoided, because the optical devices aboard Rosetta would suffer damage from the sunlight when pointing towards the comet.

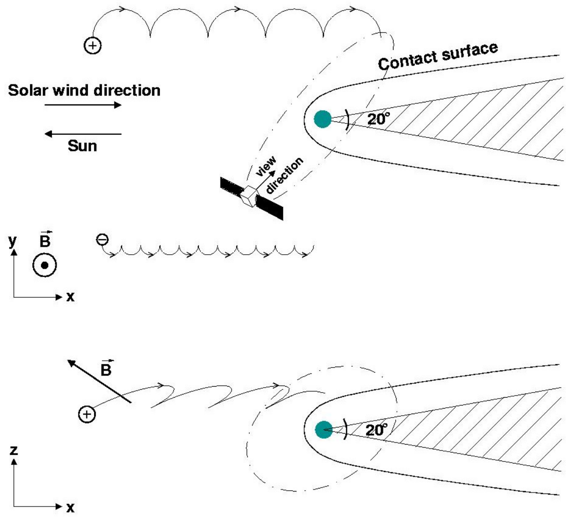

Figure 1: Non-scaled illustration of the Rosetta spacecraft being outside of the contact surface. The particle gyration is shown for two directions of the magnetic field.

The second case is shown in Figure 2, where the Rosetta spacecraft is inside the cometary contact surface. The view direction of the sensors is towards the comet. Under these circumstances the magnetic field is zero. Neutrals sublimate from the nucleus and become ionised by solar UV-radiation. Due to their radial flow, these ions can enter the sensors directly with appropriate settings of the ion attraction grids to compensate for the spacecraft charging.

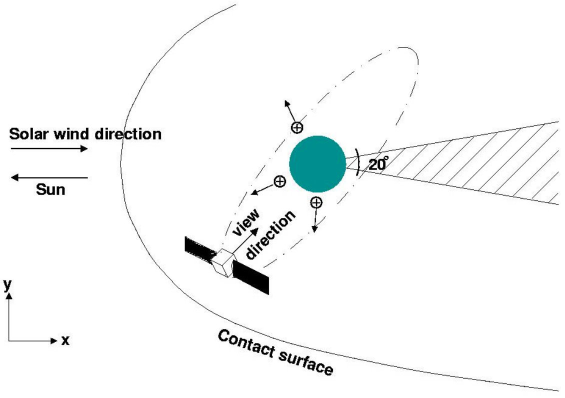

Figure 2: Non-scaled illustration of the Rosetta spacecraft inside the cometary contact surface.

4. Code Requirements

The final objective is to have a simple but sufficiently accurate tool at our disposal to estimate the efficiency of the ROSINA-sensors for ion measurements. The principal idea is to calculate the spacial distribution of the electric potential by integrating the dynamics of water-ions and electrons. Water constitutes between 60% and 80% of a comet's gaseous molecules and therefore can be considered representative for the comet's molecular composition to first order. Use is made of an explicit particle-in-cell scheme. The values of spacecraft potentials are based on the findings reported in [4]. The limit of the computational domain should extend to the undisturbed plasma and the wake-side must be open regarding the boundary conditions [2]. The area in the vicinity of the sensor's entrance must be covered by a very narrow calculation grid because there are big potential gradients. Numerical results for different views of the spacecraft are desirable. The Boltzmann factor as it is used to determine the local electron density in a negative potential cannot be applied. This is because of the mainly positive potentials Rosetta will experience. Therefore electrons must be treated as particles. Once the potential distribution is obtained, the trajectories of any desired molecular mass with arbitrary starting conditions are calculated. The design aims at a satisfactory compromise between simplicity (application on desktop computers) and reliability of results.

5. Results

The ROSINA sensors are equipped with attraction grids. Their purpose is to bias the local electric potential in order to favour ion detection. It is possible to apply voltages in the range of ± 50V to the attraction grids.

Figures 3 to 6 show some of the obtained results, where the Rosetta spacecraft is set to a potential of $\varphi_{S/C} = 3$ V. This value approximately corresponds to a heliocentric distance of 1.5 AU and a cometocentric distance of 50 comet radii.
The spacecraft is located at the wake side of the comet. The attraction grid is at $\varphi_{attr} = -10$ V. As a result, no ion with bulk velocity of 1000 m/s can enter the sensor and would be detected. The influence of the solar arrays is considerable because of their dimensions (14.13 x 2.25 m^2 each).In Figure 4 the effect of the attraction grid is shown. Again, the Rosetta spacecraft is at $\varphi_{S/C} = 3$ V. The attraction grid in turn is at $\varphi_{attr} = -50$ V. Under these conditions, the ions are able to enter the sensor and are thus detectable.

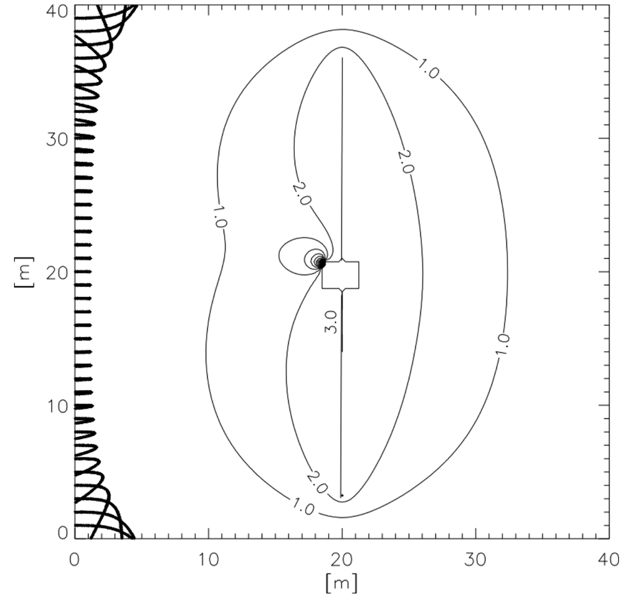

Figure 3: Plain view onto the spacecraft with trajectories of H_2O^+-molecules. The Rosetta spacecraft is at $\varphi_{S/C}$ = 3 V and located in the wake of the comet. The attraction grid of ROSINA-RTOF is at φ_{attr} = –10 V. The incoming molecules have a bulk velocity of 1000 m/s.

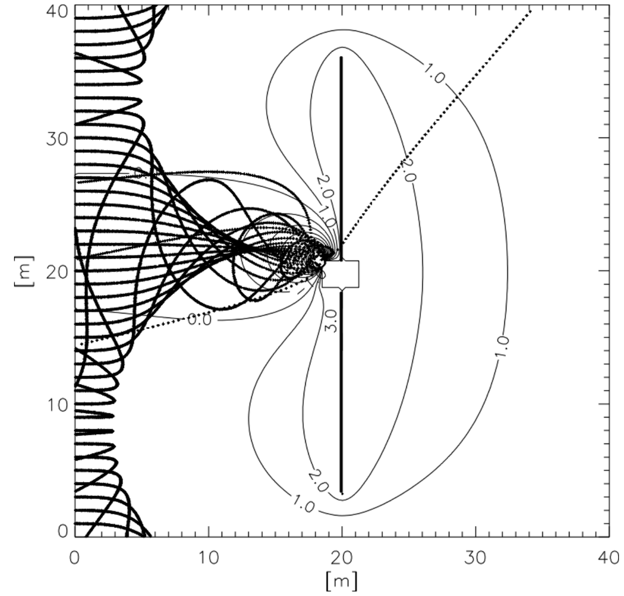

Figure 4: Plain view onto the spacecraft with trajectories of H_2O^+-molecules. The Rosetta spacecraft is at $\varphi_{S/C}$ = 3 V and located in the wake of the comet. The attraction grid of ROSINA-RTOF is at –50 V. Incoming molecules have 1000 m/s bulk velocity.

Inverse ray tracing is used to determine the origin of particles which have a clearly defined trajectory endpoint (i.e. the "initial value" is the desired entry angle and speed at the sensor inlet).

In Figure 5, the inverse trajectories end at the sensor inlet with a particle energy of 1 eV and cover the angular range from –3° to +3°. This corresponds to the angular acceptance of the RTOF sensor. The incident energy of the water molecules on the domain boundary proves to be between 0.1 and 1 eV.

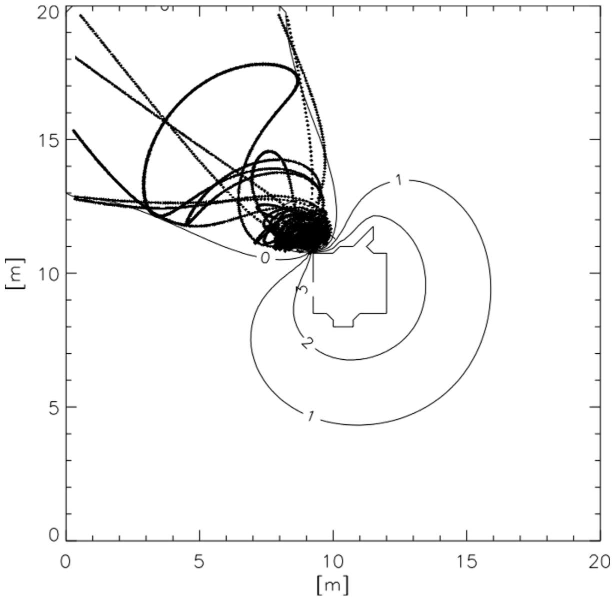

Figure 5: Side view of the spacecraft and inverse trajectories of H_2O^+-molecules with an energy of 1 eV at sensor entrance. The incident energy at the domain boundary is between 0.1 and 1 eV. The attraction grid is at φ_{attr} = –10V, while the spacecraft potential is $\varphi_{S/C}$ = 3 V.

Figure 6 depicts inverse trajectories of water molecules, arriving at the sensor with an energy of 25 eV. RTOF accepts this energy as it has been tested under lab conditions [3]. The incident energy at the domain boundary is around 16 eV.

While the situation shown in Figure 5 is likely to occur, an incident energy of 16 eV as in Figure 6 can be provided neither by the bulk nor by the thermal motion of the cometary particles. Because thermal and bulk energy of the ions are usually both one order of magnitude smaller than the electric energy with respect to the attraction grid, the incoming energy at the sensor is mainly determined by the attraction grid bias.

The ions do not reach the spacecraft in Figure 3, but they do so in Figures 5 and 6 although the potentials of the spacecraft and the attraction grid are the same in both simulations. This is because of the influence of the solar arrays, which cannot be represented correctly in the side view of a 2-D calculation.

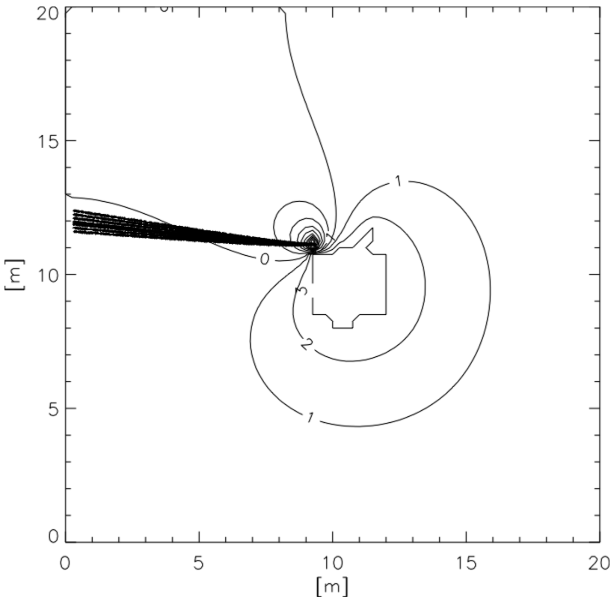

Figure 6: Side view of the spacecraft and inverse trajectories of H_2O^+-molecules with an energy of 25 eV at sensor entrance. The incident energy at the domain boundary is between 15.5 and 16.9 eV. The attraction is at $\varphi_{attr} = -10V$ and the spacecraft potential is $\varphi_{S/C} = 3$ V.

6. Conclusion

The use of an attraction grid is essential for the ion detection by the ROSINA sensors. Ion measurements within the contact surface are practicable due to the low spacecraft potential (between –0.01 eV and 7.5 eV [4]) and the collinearity of the sensor's view direction and particle flux velocity.

Outside the contact surface, it will be difficult to detect ions because of two reasons: First, the spacecraft potential will reach higher values than inside the contact surface because of the rare plasma of the solar wind. Secondly, the sensor inlets point to the comet while cometary ions outside the contact surface are carried along by the solar magnetic field as pickup-ions (non-collinearity of sensor inlets and incident particle flux).

The PIComet-simulation code for ion measurements is still under development. The most necessary features still to be implemented are:

- massive decrease of calculation time
- influence of the magnetic field
- variable grid resolution
- upgrading to 3-D

7. Acknowledgements

This work is supported by the Swiss National Science Foundation and the ESA PRODEX program.

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