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Analysis of the Cometary Plasma Environment of 67P/Churyumov-Gerasimenko Near Perihelion

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Abstract

Over the course of its two year escort phase the Rosetta spacecraft has provided various observations that furthered our understanding of the cometary plasma environment. The use of numerical simulations is essential for this understanding because they allow to place the in situ measurements in a global context, in turn, through observations the numerical models can be extended and improved.
We use the simulation code A.I.K.E.F (Müller [7]) to simulate the cometary plasma environment of 67P/Churyumov-Gerasimenko (67P/CG). Based on observations made by the Rosetta spacecraft we extend the numerical model by electron impact ionization and the anisotropic outgassing model by Hansen et al. [4]. Both extensions result in an increase in the cometary ion production rate on the dayside. Therefore, the size of the interaction region and the contained structures increases. This causes the position of the different boundaries, e.g. bow shock, to shift further away from the comet. Considering this we can explain why no bow shock crossings could be observed during the dayside excursion of Rosetta in September 2015.

Motivation for the Extensions

The ionization of cometary neutrals is the dominating process in the interaction between the comet and the solar wind. Therefore, the modeling of the different ionization sources is an integral part in simulating the cometary environment. Although photo-ionization by solar UV radiation is the dominant process, various authors, e.g. Cravens et al. [1], investigated the importance of electron impact ionization as an ionization source. Recently, Galand et al. [3] showed that in the case of a weakly active comet at heliocentric distances higher than 3.0 AU electron impact ionization needs to be taken into account in order to explain the measured electron densities. The authors showed that in certain regions the electron impact ionization frequency is of the order of the photo-ionization frequency. Previously only photo-ionization and charge exchange have been implemented in A.I.K.E.F. Therefore, it is important to include the additional ionization source in our simulations.
Another integral part in the modeling of the cometary environment is the neutral background. The most common model used for the neutral coma is the spherically symmetric model by Haser [5]. However, this is only a crude approximation as the difference between the day- and nightside and the shape of the nucleus are not taken into account. Moreover, recent observations have shown that the shape of the nucleus of 67P/CG is irregular. Therefore, different regions on the surface of the comet show different levels of activity. .

Results

We find that by including electron impact ionization the bow shock stand-off distance increases. Figure 1 shows the evolution of the bow shock position over time normalized to the ion gyroperiod t_{gyr} for two simulations: one with electron impact ionization (blue) and one without (red). Both simulations were performed for parameters representing the solar wind conditions at a heliocentric distance of 1.3 AU. Over the course of the simulation increasingly more cometary ions are picked up as the bow shock evolves. Consequently, the bow shock stand-off distance increases over time until it reaches a steady state at 7200 km for the simulation with electron impact ionization and 4800 km for the simulation without. Similar, an increase in the bow shock position can be observed for the Hansen model. Compared to the

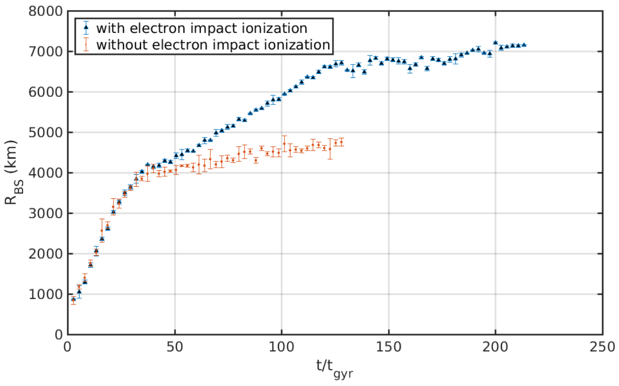

Figure 1: Evolution of the bow shock stand-off distance with time at the subsolar point for a simulation with electron impact ionization (blue) in comparison with a simulation without electron impact ionization (red). The ion gyroperiod amounts to $t_{gyr} = 2.06s$.

Haser model the neutral density computed through the Hansen model, and therefore also the ion production rate, is significantly higher on the dayside. Moreover, the anisotropy increases the asymmetry of the interaction region which affects the shape of the structures in the cometary plasma.

In September 2015 Rosetta embarked on an excursion from the vicinity of the comet up to a distance of 1500 km on the dayside. At this time simulations indicated a bow shock position of about 2000 km (Koenders et al. [6]). However, Edberg et al. [2] showed that during the excursion the magnetic field is nearly constant and no indications of a bow shock crossing could be observed. As was noted by Koenders et al. [6] the bow shock position varies strongly with the outgassing rate, neutral velocity and solar wind conditions. The fact that no variation of the magnetic field over the excursion could be observed implies that the bow shock is positioned significantly further outwards than expected.

Through the inclusion of electron impact ionization and the anisotropic outgassing model the bow shock in our simulations moved further outwards to about 8000 km. This explains why no indication of a bow shock could be observed during the dayside excursion. Furthermore, the nearly constant magnetic field up to a distance of 1500 km can be reproduced in the simulations.

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