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Low-energy ion bulk velocities and temperatures inside the diamagnetic cavity of comet 67P

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Introduction

Comets are unique objects. Due to their varying distance to the Sun, and the resulting variation of the plasma environment, they provide a unique opportunity to study plasma processes and an objects interaction with the solar wind. The comet's neutral coma is ionized through photoionization, electron impact ionization and charge exchange, creating a comet ionosphere. The newly born ions are initially cold and flowing with the neutral gas, but are eventually accelerated by the convective electric field of the solar wind and are incorporated into the solar wind flow, a process often referred to as mass loading. The solar wind is as a consequence slowed down and deflected, leading to the creation of a bow shock, a cometopause and, closest to the comet nucleus, a magnetic field free region. This region is known as the diamagnetic cavity.

The diamagnetic cavity is filled with newly born low-energy ions. Pick up processes are unimportant in this region; instead the ions are accelerated radially outwards due to an ambipolar electric field. Also important in this region is the interaction with the neutral particles. After the visit of Giotto to comet 1P/Halley it was suggested that the collisional coupling of the ions to the neutrals is dominating in this region (e.g. Cravens, 1989), making the ions flow with the same velocity as the neutrals. The resulting ion-neutral drag force was suggested to be the force balancing the outside magnetic pressure at the contact surface. This picture may, however, have to be revised after Rosetta's visit to comet 67P/Churyumov-Gerasimenko. Measurements indicate that the ions may not be coupled to the neutrals. Odelstad et al. (2018) found ion velocities in the diamagnetic cavity of 2-4 km/s, which is above the expected velocity of the neutral particles (<1 km/s). Vigren et al. (2017) estimated ion velocities of 2-8 km/s near perihelion, and modelling efforts by Vigren & Eriksson (2017) show that the strength of the ambipolar field is sufficient to, at least partly, decouple the ions from the neutrals. Further studies of the low-energy ions in this region is, however, necessary to establish the physical processes governing this region.

The Ion Composition Analyzer (ICA, Nilsson et al., 2007) on board Rosetta was measuring ions down to energies of just a few eV. The substantially negative spacecraft potential of Rosetta has, however, distorted the low-energy data, which has therefore not been fully exploited. In recent studies by

Bergman et al. (2020a,b), the influence of the spacecraft potential has, however, been modelled, making it possible to study the low-energy ions in more detail. In the current study we aim to use the method developed by Bergman et al. (2020a,b) to estimate the bulk velocity, temperature and flow direction of the low-energy ions observed by ICA inside the diamagnetic cavity.

Method

Data

ICA is a mass resolving ion spectrometer, measuring the three-dimensional distribution function of positive ions within an energy range of a few eV/q to 40 keV/q. The nominal FOV is 360ºx90º, and the time resolution is 192 seconds. During the mission ICA was occasionally run in a mode with a higher time resolution of 4 seconds. In this mode, the instrument is measuring in 2D and only sweeps over the lowest energies (up to ~80 eV). Fast changes in the low-energy ion environment can then be captured. In this study, we only use data obtained with this high time resolution mode. In total ~80 events of high time resolution data have been obtained by ICA inside the diamagnetic cavity. One energy-time spectrogram is, as an example, shown in Figure 1.

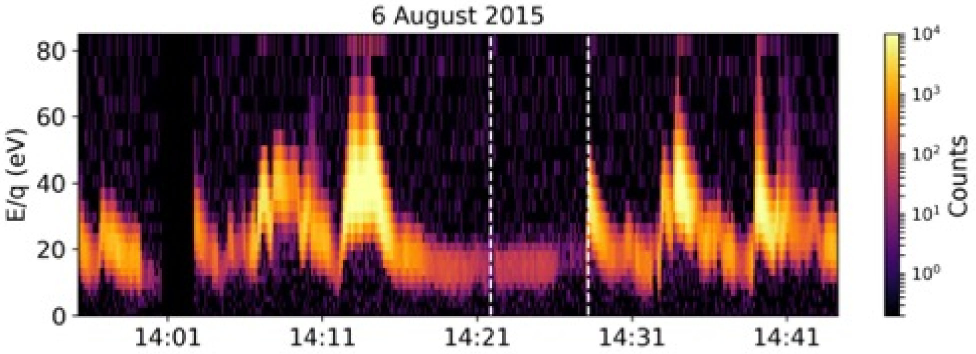

Figure 1. Energy-time spectrogram from ICA obtained with the high time resolution mode. Between the white dashed lines the spacecraft was located within the diamagnetic cavity.

Simulations

We use the Spacecraft Plasma Interaction Software (SPIS, Thiébault et al., 2013), and the method developed by Bergman et al. (2020a,b), to model the distortion of the velocity distribution of the low-energy ions, caused by the negatively charged spacecraft. The principle is illustrated in Figure 2. From an initially Maxwellian velocity distribution with bulk velocity v and temperature T, the model provides a resulting detected energy distribution and a flux distribution over the azimuthal sectors of the instrument. By comparing the model results for different bulk velocity-temperature combinations to the ICA data, conclusions can be drawn about the initial velocity distribution of the detected ions.

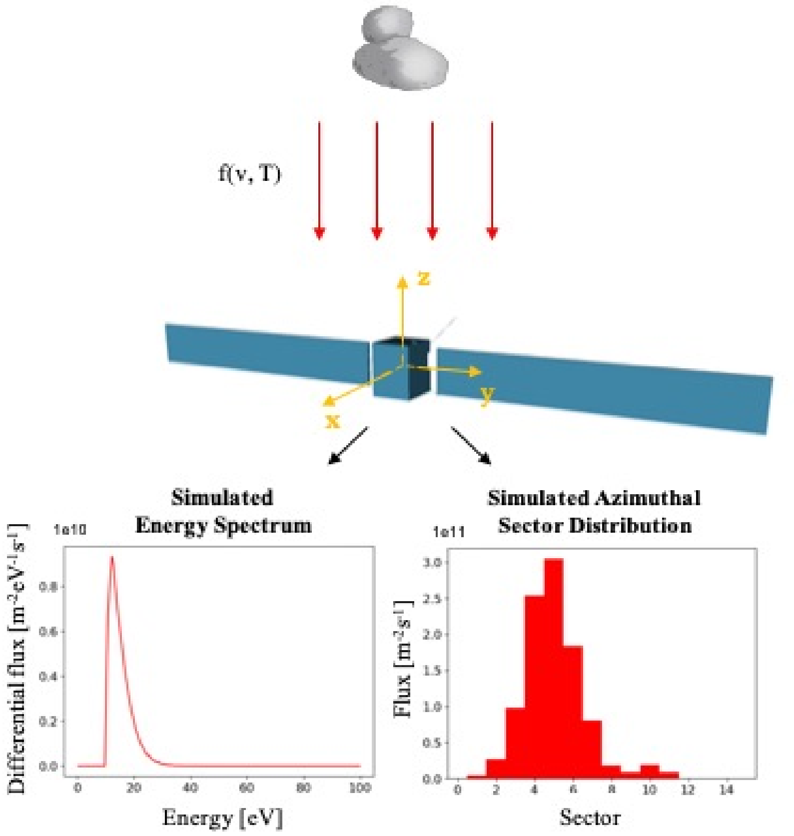

Figure 2. Simulation principle. An initially Maxwellian velocity distribution with bulk velocity v and temperature T results in a detected energy spectrum and azimuthal sector distribution depending on the relation between v and T and the value of the spacecraft potential Us/c. In this example v = 4 km/s (in the –z direction, between sector 4 and 5), T = 2 eV and $U_{s/c} = -10$ V.

Expected Results

In this presentation, we will show the most probable bulk speeds and temperatures of the low-energy ions inside the diamagnetic cavity, as estimated from the ICA data. We will also use the simulation results from Bergman et al. (2020a,b) to estimate the flow direction of the ions.

Acknowledgements

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