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Cold electrons at a weakly outgassing comet

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The Rosetta spacecraft rendezvoused with comet 67P/Churyumov-Gerasimenko in August 2014 and escorted it for two years until September 2016. The plasma surrounding the comet was probed by the Rosetta Plasma Consortium (RPC), comprising five instruments. The Langmuir Probe (RPC/LAP; Engelhardt et al., 2018) and Mutual Impedance Probe (RPC/MIP; Wattieaux et al, 2020; Gilet et al., 2020) measured a cold population of electrons (< 1 eV) within the cometary environment, that was persistent throughout the mission.

Cometary electrons are typically produced at 10 eV through ionization of the neutral gas coma. This is either through photoionization, by absorption of an extreme ultraviolet (EUV) photon, or electron-impact ionization, by collisions of energetic electrons with the coma. Cold electrons are formed by cooling the warm, newly born electrons, through inelastic collisions with the cometary neutrals. Assuming they flow radially away from the nucleus, the electron cooling should only be significant for the high outgassing rates found around perihelion ($Q > 3 \times 10^{27}$ s^{-1}). However, the cold population was observed at large heliocentric distances (> 3.5 au) and very weak outgassing rates ($Q < 10^{26}$ s^{-1}).

We have developed the first 3D collisional model of electrons at a comet, featuring a spherically symmetric coma of pure water. Electric and magnetic fields are self-consistently calculated using a fully-kinetic, collisionless Particle-in-Cell simulation model (Deca et al., 2017; 2019), which are used as an input for the test particle model. Electron-neutral collisions are treated as a stochastic process. The collision processes include elastic scattering, inelastic excitations, and electron-impact ionization.

With the test particle model, we demonstrate that electrons are trapped in an ambipolar potential well around the nucleus. This greatly increases the efficiency of collisional processes compared to the case of radial outflow. A cold electron population is formed at weak outgassing rates ($Q = 10^{26}$ s^{-1}), far below the threshold for cooling under radial outflow.

We quantify the increased efficiency of electron collisions when using the complex electric and magnetic fields, compared to radial outflow. The location of the electron cooling exobase is calculated accounting for electron trapping and compared with the cold electron measurements from Rosetta. This explains the cold electron observations at low outgassing rates.

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