MEASUREMENTS OF THE ELECTROSTATIC POTENTIAL OF ROSETTA AT COMET 67P

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ABSTRACT

We present and compare measurements of the spacecraft potential ($V_{S/C}$) of ESA:s Rosetta spacecraft, currently in orbit around comet 67P/Churyumov-Gerasimenko, by the Langmuir probe (RPC-LAP) and Ion Composition Analyzer (RPC-ICA) instruments. $V_{S/C}$ has mainly been negative, driven so by the high ($\sim$5 eV) temperature of the coma photoelectrons. LAP only picks up a portion of the full $V_{S/C}$ since the two probes, mounted on booms of 2.2 and 1.6 m length, respectively, are generally inside the potential field of the spacecraft. Comparison to the minimum energy of collected positive ions by ICA shows that this portion varies between 0.7 and $0.9V_{S/C}$, with generally good correspondence between the two instruments except when local ion production is weak and accelerated ions dominate the flux.

Key words: Rosetta; comets; ESA; spacecraft potential; Langmuir probe; RPC-LAP; RPC-ICA; electrostatic analyzer; plasma; coma; ionization.

1. INTRODUCTION

The European Space Agency's Rosetta spacecraft arrived at comet 67P/Churyumov-Gerasimenko in August 2014 and has since then been immersed in the cometary plasma environment. At arrival, the heliocentric distance was 3.5 AU, decreasing to 1.27 AU at perihelion one year later and since then once more increasing. The instruments of the Rosetta Plasma Consortium (RPC) [1] have thus been able to follow the evolution of this environment and the varying spacecraft-plasma interaction over an approximately four orders of magnitude variation in plasma density, driven by an order of magnitude change of solar illumination from rendez-vous to perihelion and varying distance of Rosetta to the comet nucleus.

Throughout the mission, the neutral density has generally been insufficient to effectively cool the coma photoelectrons, leading to an observed electron temperature by the Rosetta Langmuir probe instrument (RPC-LAP) of on the order of 5 eV [3]. The cold plasma ions and weak spacecraft photoemission cannot balance the flux of such warm electrons to the spacecraft, which has thus typically been negatively charged (often by several tens of volts) [9]. This greatly affects the particle and dust measurements by instruments on the spacecraft main body, e.g. effectively shielding the spacecraft from small negatively charged dust grains [4].

The LAP spacecraft potential measurements only represent a portion of the full spacecraft potential ($V_{S/C}$) due to the fact that the two probes, being mounted on booms 2.2 and 1.6 m long, respectively, are generally inside the potential field of the spacecraft [5]. When local production dominates, which is likely most of the time, information about $V_{S/C}$ can also be derived from the collection of low energy ions by the Ion Composition Analyzer (RPC-ICA) [7, 8], located on the main spacecraft body, using the minimum energy of collected positive ions. Comparison of the two gives information on the electrostatic potential around Rosetta and allows determination of the fraction of $V_{S/C}$ observed by LAP.

2. INSTRUMENTATION AND MEASUREMENTS

2.1. Spacecraft potential measurements by RPC-LAP

RPC-LAP consists of two spherical Langmuir probes (LAP1 and LAP2) with radii of 2.5 cm, mounted on 15 cm stubs on the tips of booms of length 2.24 m and 1.62 m, respectively. LAP1, being mounted on the longer boom at an angle of 45° off nominal nadir, is positioned to minimize the disturbances from the spacecraft sheath and wake effects without violating the field of view of other instruments [2]. In this Paper, we include only measurements from LAP1.

LAP is a very versatile instrument, in principle capable of obtaining the electron density and temperature, ion density and flow speed, spacecraft potential, mean ion mass and integrated UV flux. However, the highly variable and evolving plasma environment of comet 67P makes many of these measurements difficult in practice, particularly when it comes to consistent automatic analysis covering longer time periods. The spacecraft potential measurements stand out in this regard by providing consistent and reliable results during the bulk of the mission.

LAP $V_{\text{s/c}}$ measurements can be obtained from Langmuir probe bias potential sweeps, where the probe bias potential is sequentially stepped through a range of values, the maximum range being from -30 V to +30 V, with the spacecraft as floating ground. When the probe is at a negative potential w.r.t. the plasma immediately surrounding it, all the photoelectrons emitted from its surface are repelled away from the probe and contribute to the probe photoemission current, which hence saturates at a value independent of the actual value of the probe potential. When the probe becomes positive w.r.t. the surrounding plasma, a portion of the emitted photoelectrons are attracted back to the probe and the photoemission current decreases exponentially with increasing probe potential. This gives rise to a sharp inflection point in the sweeps at the potential of the local surrounding plasma, henceforth denoted V_{ph}, which in the absence of spacecraft sheath effects is equal to the negative of $V_{\text{s/c}}$. If the probe is located within a few Debye lengths of the spacecraft, the potential field of the charged spacecraft will persist at the location of the probe and this method only finds some fraction $1/\alpha$ of the total $V_{\text{s/c}}$:

$$V_{\text{ph}} = -\frac{V_{\text{s/c}}}{\alpha}. \tag{1}$$

$V_{\text{s/c}}$ measurements can also be obtained from a floating probe, for which the currents naturally sum to zero. Using floating probes is the standard method for measuring $V_{\text{s/c}}$ and electric fields in sufficiently dense plasmas [6]. Although there is no a priori reason to expect the fraction of $V_{\text{s/c}}$ picked up by this method to be the same as the fraction picked-up by the bias potential sweeps, in many cases they are empirically found to match up very well. While LAP bias potential sweeps can only be carried out once every 32 s at best, potential measurements from a floating probe can be obtained at a sampling frequency of up to 60 Hz, thus greatly increasing the time resolution of $V_{\text{s/c}}$ measurements. Although bias potential sweeps are much more prevalent throughout the mission, the latter kind of $V_{\text{s/c}}$ measurements are used here because the higher time resolution is advantageous for comparison to ICA data.

2.2. Obtaining the spacecraft potential from RPC-ICA

RPC-ICA is an electrostatic analyzer for ions, located on the spacecraft main body and oriented so that both the sun and nucleus directions are in its field of view during nominal spacecraft pointing. In the presence of detectable levels of locally produce ions, the spacecraft potential can be obtained from the lowest energy $E_{\text{ion,threshold}}$ of collected ions, since these have been accelerated by the spacecraft potential and gained an energy $-qV_{\text{s/c}}$, q being the ion charge. Its location on the spacecraft main body means that, unlike LAP, ICA captures the full value of $V_{\text{s/c}}$. However, the ICA energy spectra suffer from an unknown energy offset, typically on the order of 10 eV, but highly dependent on the instrument temperature. LAP measurements are needed for comparison to determine the value of this offset. The nominal time resolution of ICA is 192 s. The field-of-view of the instrument is then 90x360 and the energy range is 5 eV-40 keV. By reducing the energy range to 5-95 eV and the field-of-view to 5x360 (a two dimensional measurement) we can run the ICA in a operational mode with a 4 second time resolution to capture the highly variable nature of the cometary plasma environment.

3. RESULTS AND DISCUSSION

Figure 1 shows ICA ion spectra and LAP1 floating potential measurements V_{float} during a period of high ICA time resolution and stable sensor temperature on August 25, 2015. There is a strong correlation between V_{float} (orange line) and $E_{\text{ion,threshold}}$ (white line), confirming that both instruments are indeed tracing the spacecraft potential. A total least squares (TLS) linear fit of V_{float} to $E_{\text{ion,threshold}}$ (not shown) gives a slope of 0.76 and and an intercept of -6.89, which indicates that a correction factor α of 1.32 should be applied to V_{float} in order to obtain the full $V_{\text{s/c}}$ and that the ICA energy offset is 9.1 V. The red line in Figure 1 shows the sum of the corrected V_{float} and the ICA offset, demonstrating the good quality of the fit.

Figure 2 shows another example from September 25, 2015, where the fit is not as good. It can be seen that the correlation between V_{float} and $E_{\text{ion,threshold}}$ is lost when the ion fluxes observed by ICA becomes too weak, in which case $E_{\text{ion,threshold}}$ appears to overestimate $V_{\text{s/c}}$. We tentatively attribute this to the local ionization being intermittently lost and the ion flux being dominated by an ion population produced further away from the spacecraft and then accelerated towards it by an ambient electric field. Another possibility is that the locally produced ions are still present, but outside the ICA field of view, which may be affected by the spacecraft potential and attitude.

Figure 3 shows an overview of the derived correction factor α for all available high time resolution ICA measurement blocks with stable sensor temperatures and concurrent high time resolution LAP V_{float} measurements, annotated by the respective coefficient of determination R^2 for each block. Most blocks give α between about 0.7 and 0.9, with correlation coefficients in excess of 0.7. The three blocks with lower α and R^2 include substantial periods of weak ion flux.

Figure 1. ICA high time resolution ion energy spectra under stable sensor temperature. LAP1 spacecraft potential measurements (orange line) correlate well with the ion threshold energies (white line). Also shown: LAP1 spacecraft potential measurements corrected by a factor of 1.32 and with an offset of 9.1 V (red line).

4. SUMMARY AND CONCLUSIONS

We have combined measurements by RPC-ICA and RPC-LAP to determine what fraction of the spacecraft potential is observed by LAP. We find in general a good correspondence between the two instruments, increasing our confidence in the their accuracy. The correlation disappears intermittently, coincident with weakened ion fluxes. This is interpreted as temporary loss of local ionization, at least within the ICA field of view, causing the ion flux into the instrument to be dominated by accelerated ions, the energy of which is not strongly dependent on $V_{S/C}$. The fraction of $V_{S/C}$ picked up by LAP1 is found to vary between about 0.7 and 0.9, indicating that a correction factor between about 1.1 and 1.4 should be applied to the LAP1 measurements to obtain the full $V_{S/C}$.

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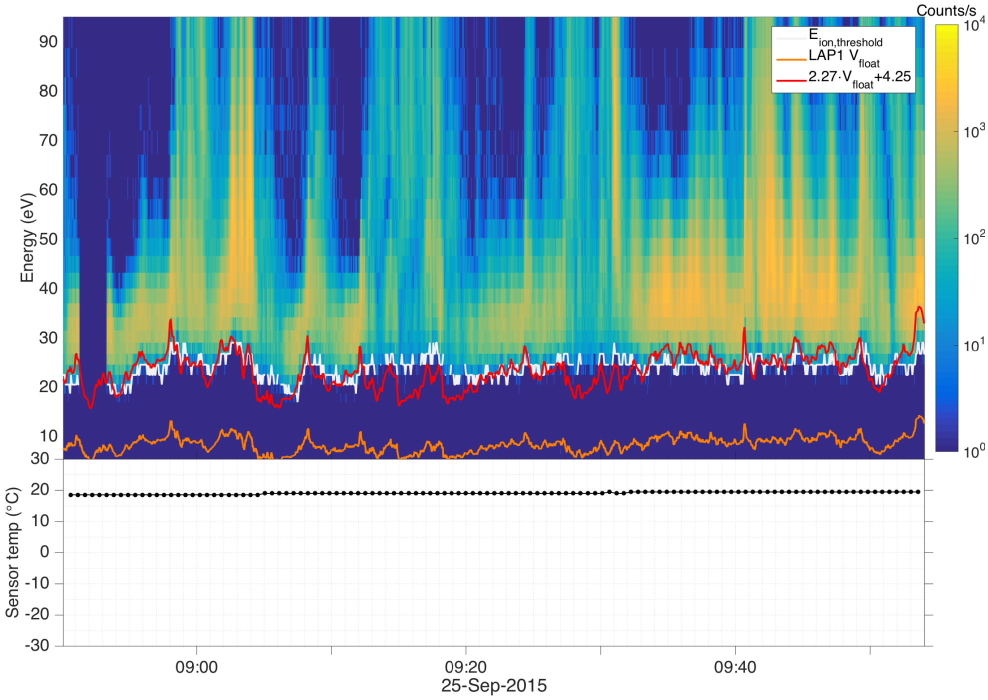

Figure 2. ICA high time resolution ion energy spectra under stable sensor temperature but intermittently subdued local ionization. The correlation between LAP1 spacecraft potential measurements (orange line) and the ion threshold energies (white line) is lost during periods of weak ion flux.

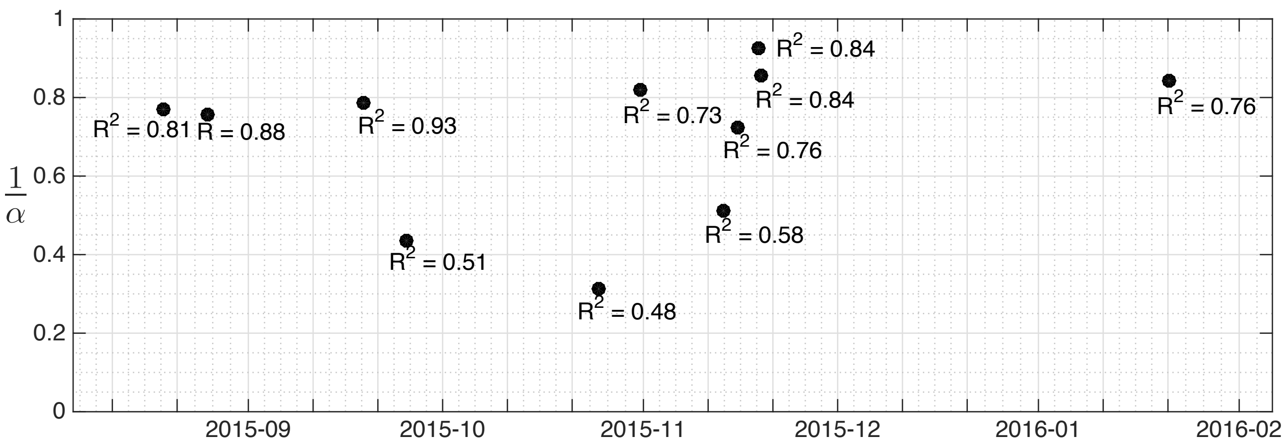

Figure 3. Overview of the fraction $1/\alpha$ of V_{float} picked up by LAP1 annotated with the R^2 coefficient of determination between V_{float} and $E_{ion,threshold}$ for each measurement block.