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Initial Results from the Rosetta LAP Instrument

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Abstract

This work is based on the commissioning data from the Rosetta Langmuir probe instrument (aka LAP) received in May 7-11, 2004. At first, we worked on ESA's hierarchy and structure for the LAP data and wrote a base code to browse through these data and display them in a typical current vs bias voltage curve. Then we improved the graphical functionalities and features of this browsing software now called *PDS_browser*, and added a model to fit the instrument measurements in order to evaluate its performance and derive some physical parameters. The software indeed allowed to get some realistic values for the spacecraft potential, and the different current contributions as well as for the temperatures. Finally, when plotted against time, the data showed a predictable behaviour and the different parameters seem to be well correlated amongst each other though they don't really match with measurements from the ACE spacecraft, probably because the properties of the solar wind are not homogeneous on such a large scale.

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1 Introduction

The Rosetta probe mission is a huge ESA (European Space Agency) project involving many European countries and with a budget of around 1M euros. Its aim is to investigate at a close range a comet (currently 67P/Churyumov-Gerasimenko) with a broad variety of onboard instruments allowing to probe the comet with respect to different aspects (nucleus inhomogeneities, chemical composition, plasma environment. . .).

Besides the study of the comet, since it's a very long journey ¹ (see Fig. 1) to reach it (around 10 years), Rosetta will provide the opportunity to study Mars and Earth ionosphere and magnetic field (during fly-bys). In addition, Rosetta will have a close look at 2 asteroids, Steins and Lutetia, because like comets, asteroids are witnesses of the solar system prime and could be a key for the understanding of the initial accretion of the solar system. And finally, even though it's not its primary goal, Rosetta can gather precious informations about solar wind and interplanetary environment thanks to RPC (see below) instruments; though it will be on power-saving mode most of the time during the journey to the comet.

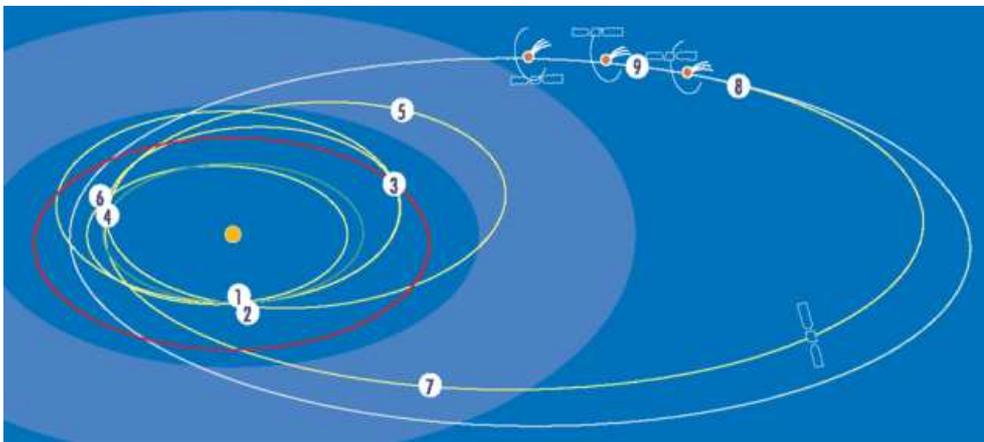


Figure 1: Rosetta journey. Copyright: ESA.

One of the instruments, the dual Langmuir probe instrument (aka LAP) was designed and

¹Rosetta journey:

1. Launch, 2 March 2004.
2. First Earth swingby, 3 March 2005.
3. Mars swingby, 26 February 2007.
4. Second Earth swingby, 14 November 2007.
5. Asteroid Steins flyby, 5 September 2008.
6. Third Earth flyby, 11 November 2009.
7. Asteroid Lutetia flyby, 10 July 2010.
8. Final manoeuvres to enter comet orbit in 2013.
9. Starting comet investigations in 2014.

built at the Swedish Institute of Space Physics in Uppsala where this project work has been conducted. LAP is one of the five sensors belonging to the Rosetta Plasma Consortium (aka RPC) which is in charge of the wave and plasma studies in Rosetta mission. Those five sensors: the Langmuir Probe (LAP), the Ion and Electron Sensor (IES), the Ion Composition Analyser (ICA), the Fluxgate Magnetometer (MAG), and the Mutual Impedance Probe (MIP) have been particularly designed in order to monitor the coma and tail composition and structure as well as their interactions with the solar wind E-M field and the interplanetary medium. Figure 2 shows RPC instruments on Rosetta.

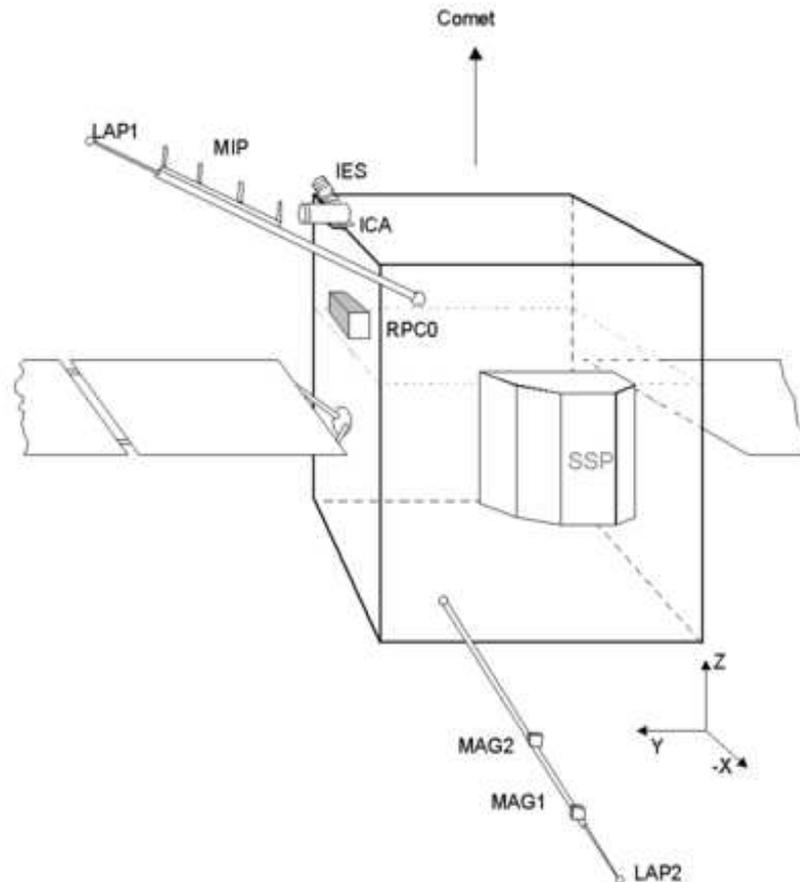


Figure 2: RPC instruments on Rosetta.

This document is the final report on a project consisting of two main parts:

- Writing of a software for browsing and analyzing one of the data types provided by LAP, the so-called probe bias sweeps.
- Using the software for analyzing the probe bias sweeps acquired during the RPC operations in May 7-11, 2004.

The document is structured as follows: after this introduction, section 2 briefly describes the LAP instrument, and section 3 gives the theoretical model used to understand the probe bias sweeps. The available data are described in section 4, while the software written in this project is described in section 5. Section 6 contains the data analysis. Finally, section 7 contains a discussion of the results and ideas for the future.

2 Langmuir probe overview

The Rosetta Langmuir probe is a very versatile though quite simple instrument: it is basically a 2.5 cm radius titanium sphere mounted on a 15 cm stub ending with an aluminium which can be attached to a spacecraft boom, see Fig. 3. The sphere and the stub are coated with



Figure 3: Rosetta Langmuir Probe.

titanium nitride which conducting and hardness properties are suitable for this instrument, since its principle is to measure a current while a certain bias voltage is applied (or vice-versa). From this measurement, one can then derive fundamental plasma properties such as plasma density, electron (and ion) temperature and flow velocity.

What makes the dual Langmuir probe instrument such an efficient tool is the fact it can be operated in different modes thanks to the associated electronics and the possibility to use two Langmuir probes together to perform some complementary measurements. Thus, it can not only derive the essential plasma properties but also informations such as electric field measurements up to 8 KHz, spacecraft potential, integrated solar UV flux, and dust particle impacts.

Though, as said above, LAP can be operated in several different modes, this work was based on only one type of measurement mode: voltage bias sweep. The principle is to vary the probe potential with respect to the spacecraft's, V_B , and record the collected current I_p (created by the electrons (or ions) colliding on the probe). If the potential is positive with respect to the plasma, electrons (or seldom negative ions) will be attracted by the probe and thus it is possible to derive the electron density and temperature in the plasma from these measurements. While if the potential is negative, the positive ions are collected and the interesting value to derive in this case is the average ion drift kinetic energy. Let's not forget nevertheless that some electrons are to hit the probe even when its potential is negative just because of their thermal kinetic energy and the fact that the probe is not still with respect to the solar wind flow; and the same goes for the positive ions.

3 Theoretical model

3.1 The environment

Since this work is mainly based on interplanetary plasma measurements, it is appropriate to set the basic background about interplanetary medium and solar wind environment.

The solar wind is a flow of more or less energetic particles blown away from the sun, which spreads radially (not isotropically though) in all directions. It usually carries mainly electrons and ionized hydrogen (H^+), a few ionized helium (He^{2+}) and seldom some heavier ions like O^+ . It also features an embedded magnetic field, remnant of the Sun's own magnetic field, which is frozen into the plasma itself and is a great deal of importance because of its effects on the other magnetic fields of the solar system bodies. However, this magnetic field has a weak influence on the statistical properties of the plasma and on the probe measurements so it will not be of our concern in this work.

The solar wind properties can vary on a large scale because they are tightly bound to the solar activity (variations within a factor of two are quite common), however under usual conditions of solar activity one can observe some typical values in the interplanetary medium as the ones in Table 1.

Proton density	6.6 cm^{-3}
Electron density	7.1 cm^{-3}
He^{2+} density	0.25 cm^{-3}
Flow speed (nearly radial)	450 km.s^{-1}
Proton temperature	$1.2 \times 10^5 \text{ K}$
Electron temperature	$1.4 \times 10^5 \text{ K}$

Table 1: Observed average solar wind properties near Earth orbit.(from [1])

Finally, this medium is of course also bathed in electro-magnetic radiations coming from the Sun, especially visible, ultra-violet, and infrared light since the Sun can be considered as a black body with maximum emission in the visible green, around 530 nm. We will see the importance of this point as the photoelectrons emission will take a dominant part in our model. Some harder radiations (X Rays) and higher energy particles can also occur subsequently to more violent events such as solar flares or coronal mass ejections (CMES).

3.2 Plasma model

Since a plasma is a gas of charged particles, the motion of these particles is described by a statistical distribution and by electromagnetic interactions if there are any. Space plasma are very tenuous so they are considered collisionless, but the statistical distribution for this model is nevertheless chosen to be Maxwellian. Thus, the movement of a particle of species j , if there are no electromagnetic interactions will be in a random direction, with a speed given by the Maxwellian thermal velocity,

$$v_{th} = \sqrt{\frac{k_B T_j}{m_j}} \quad (1)$$

where m_j is the mass of particle of species j , T_j is the temperature of particle of species j in the plasma and k_B is the Boltzmann constant. Of course in a solar wind plasma the particles also have the speed of the flow with respect to a slow moving frame of reference like Rosetta probe.

Then for electromagnetic interactions, the starting point is to consider the electrostatic potential generated by a point particle of charge q given by

$$V(r) = \frac{q}{4\pi\epsilon_0 r} \quad (2)$$

where r is the distance to the particle and ϵ_0 is the vacuum electric permittivity. In a plasma, this charge will attract charges of opposite sign which will create a cloud around it, therefore decreasing the influence of this potential because of their opposite charge. One can show that the net result of this shielded potential is:

$$V(r) = \frac{q}{4\pi\epsilon_0 r} e^{-r/\lambda_D} \quad (3)$$

where λ_D is called the *Debye length* and is given by

$$\lambda_D = \sqrt{\frac{\epsilon_0 k_B T}{nq^2}} \quad (4)$$

where T is the temperature of the plasma, and n is the density number (from [6] and [7]). The Debye length thus represents the scale size below which the strength of the potential from individual charges is significant; and for a given charged object, the plasma contained in the volume surrounding the object below this distance is called the *Debye sheath*.

The point here is not about the E-M interactions between the particles themselves because their charge is ridiculously small compared to the distance between them, that they barely interact. However, for a large scale object like a spacecraft, this potential has to be taken into account. The reason is even if the net charge of a plasma is null, at equal ion and electron temperatures the electron flux is higher than the ion flux (because electrons have higher velocities due to their smaller masses) so the object will be hit more often by electrons and will eventually become negatively charged with respect to the plasma. Then, as a charged body it will be responsible for an electrostatic potential characterised with a certain Debye length as seen above.

Consequently, if one wants to measure some plasma characteristics without having the influence of the spacecraft, it has to be done out of the spacecraft's Debye sheath and this is the main reason why Langmuir probes are mounted on long booms far from the spacecraft hull (for rotating spacecrafts, they can even be attached to long wires). In Rosetta's case, the LAP1 probe is mounted on a 2010 mm boom and LAP2 is on a 1395 mm one. Of course, for the determination of the length and the deployment direction of the booms, some other factors such as the shadow created by the spacecraft and the distance between the two probes (as well as the other instruments mounted on the booms) have been considered.

3.3 Photo-emission

Since a lot of radiation, including UV, are emitted from the sun and since the spacecraft and the probe are conductors, they are subject to photo-emission; that's to say some electrons are

stripped out when some photons with the required energy hit the surface of a conductor. As a result, some additional electrons are emitted from the spacecraft, giving an increased number of electrons close to the spacecraft compared to the unperturbed plasma electron density.

Besides, the effects will be different whether the spacecraft (and probe) potential is positive or negative: if it is positive, the electrons will just be stripped out and pushed away and the photo-electrons density will just decrease with the distance from the spacecraft, whereas if it is negative some of them will be pulled back to the spacecraft and will be seen as a constant cloud close around the spacecraft.

Though the photo-emission is usually small (on the order of 100 mA/m²) for a conductor exposed to UVs from the sun, it is definitely non negligible compared to the random electron current usually found in the solar wind, and it is usually the major contribution on the ion collection side.

3.4 Probe currents

Since the raw informations we get from Langmuir probes are currents and voltages, it is important to have a precise model of the currents created by the different contributions in order to analyse the measurements from the probes. As said above, we still consider an isotropic and collisionless plasma with no magnetic field and, as it is the case with Rosetta, some spherical Langmuir probes featuring an homogeneous surface.

The size of the probe also plays a role here because above a certain size, the Debye screening effect becomes so important that the Debye sheath will change with the charge accumulation. Hence, if we denote the probe radius as r_p , when $r_p \ll \lambda_D$ the Debye sheath is weak and the motion of a single charge is independent of the motion of other charges and mainly governed by the probe potential; this regime of particle collection is then called *Orbital Motion limited* (aka OML). Whereas when $r_p \gg \lambda_D$ the collection is said to be *Sheath limited* because the Debye screening effect is important and the particles motion will be greatly influenced by the Debye sheath.

Fortunately, the Debye length in an interplanetary medium is within the range 1-50 meters and the probes are 2.5 cm of radius so the OML approach should apply for all this work and one shouldn't have to care about the effects of the Debye sheath generated by the probe. Thus, from the original work by Mott-Smith & Langmuir (1926), one can obtain expressions for the electron and ion currents as functions of the probe voltage with respect to the plasma for which we have:

$$V_p = V_s + V_b \quad (5)$$

where V_s is the spacecraft potential with respect to the plasma and V_b is the applied bias voltage with respect to the spacecraft. We also have the random current of species j defined as:

$$I_{j0} = A_p n_j q_j \sqrt{\frac{k_B T_j}{2\pi m_j}} \quad (6)$$

where A_p is the area of the probe, n_j the number density of the particle species, and q_j the charge of the particle species.

Then for a positive bias potential the electron and ion currents are:

$$I_e = I_{e0}\left(1 + \frac{V_p}{T_e}\right) \quad (7)$$

$$I_i = -I_{i0}e^{-V_p/T_i} \quad (8)$$

and for a negative bias potential:

$$I_e = I_{e0}e^{V_p/T_e} \quad (9)$$

$$I_i = -I_{i0}\left(1 - \frac{V_p}{T_i}\right) \quad (10)$$

where all the electron temperature T_e and the ion temperature T_i in the plasma are in electron-volts. For a supersonic flow like the solar wind, the relevant energy parameter for the ion gas is not the temperature but the drift energy, which gives modifications to equations (6), (8) and (10). However, we do not expect the ion current derived in this work to be physically meaningful, as the ion drift energy in the solar wind is 1 keV which is much above the range of our probe sweeps. We therefore keep the expressions (6), (8) and (10), having in mind that the value of T_i could just as well be interpreted as $m_i v_i^2/2$.

Finally, last but not least, the photoelectron emission is modelled as:

For the photoelectrons ripped out of the probe itself:

$$I_f = -I_{f0} = \text{const} \quad \text{if } V_p < 0 \quad (11)$$

$$I_f = -I_{f0}e^{-V_p/T_{p0}} \quad \text{if } V_{probe} > 0 \quad (12)$$

A more complete model could include two photoelectron temperatures, as suggested in e.g. Ref. [5].

The probe will also collect photoelectrons emitted by the spacecraft, including the solar panels and the booms. If the photoelectron cloud is homogeneous on the scale size of the of the probe, it is reasonable to assume that these photoelectrons are collected just as the plasma electrons but with V_p replaced by V_b in (7) and (9) since the photoelectrons are emitted from the spacecraft. We thus model this current as:

$$I_s = I_{s0}e^{V_b/T_s} \quad \text{if } V_b < 0 \quad (13)$$

$$I_s = I_{s0}\left(1 + \frac{V_b}{T_s}\right) \quad \text{if } V_b > 0 \quad (14)$$

4 The data

One common point to any scientific experiment is to produce and store data in a format easily accessible and exploitable by the world wide scientific community so that any scientific group can use these data to produce new results.

One widely used archive system in the Planetary science domain is the Planetary Data System (PDS) which is an archive of data sponsored and managed by NASA (National Aeronautics

and Space Administration) for its planetary missions, but the same format has also been adopted by ESA in order to gather all planetary data in a common, unified, archive system. Hence, the data from LAP experiment (as well as all the data from Rosetta mission) are to be archived in ESA's Planetary Science Archive (aka PSA) to PDS standards, with a mirror at the Small Bodies Node based at the University of Maryland College Park.

However, PDS is also a commonly employed term for the format of the data which are to be stored in a PDS data archive, that's to say the data have to be written in files with respect to certain conventions. For example, one of the requirements for Rosetta data format is to be highly human readable, i.e one should be able to read directly the data or the header files with a simple text editor. This is certainly not the best way in terms of storage space but it is aimed on clarity and ease of search for the ones who are to use the data later.

This work was based on two kind of files: the data files themselves and the label files which go with them. The data file name is of this kind:

RPCLAPyymmdd_XXXX_RDSxxNS.TAB, which directly indicates that,

- the data are from a Rosetta Plasma Consortium mission (RPC), more precisely from the Langmuir Probe experiment (LAP).
- the date of the data acquisition (yymmdd).
- the ordering of this data file thanks to a four digits alphanumeric counter (XXXX).
- the kind of operation performed by LAP to acquire these data (RDSxxNS); here RDS means it's a bias voltage sweep and NS means it is taken in normal mode telemetry. The first digit after RDS indicates whether the data come from the Rosetta Langmuir probe 1 or the probe 2.

The contents of this kind of data file simply consists in four columns, comma separated, each row representing one measurement point.

- The first column is the time of the measurement in this format: yyyy-mm-ddThh:mm:ss.ssssss.
- the second one is the spacecraft own clock time stamp, in case the time calibration has to be redone.
- the third one is the current measurement in telemetry units.
- and the last one is the voltage bias also in telemetry units.

The label file which goes with each one of the data files is named exactly the same except for the extension which is now .LBL instead of .TAB. It contains numerous relevant human readable informations about the data file, especially a lot of specifications about the measurement like the kind of sweep, the instrument mode, the range of the bias . . . etc.

There are several other types of file just for the LAP experiment itself, including some house-keeping files and some headers, but the two mentioned above plus another unique index file were the only one which were needed for this work.

5 The browser

The aim of this work is to be able to analyze the first LAP data sent by the probe, during the commissioning period of the instrument. Though the primary goal is to check if the instrument work as planned and to evaluate its performance, one can expect to extract some physical parameters characterizing the solar wind and interplanetary medium if the space weather conditions are favorable.

To do so, it is necessary to build a browsing software capable of extracting the data from the files, calibrating them into physical units, displaying them in a clear current vs bias voltage graph, displaying the informations relative to the sweep and finally trying to fit the measurements to a theoretical model in order to derive some physical parameters. All of this preferably embedded in an easy to use graphical interface (aka gui).

Since the execution speed and the portability are not a requirement for this work, the programming language which has been used is Matlab. This one is rather convenient to act on long tables of data, to display some graphs, to fit the data and since it is interpreted, the code is easy to write, and it can be read and reused easily in the future. The browser can thus be launched from a Matlab prompt by the command `browse` (i.e interpret `browse.m` file with Matlab) if the user is placed in the main directory of the software (currently called LAP).

5.1 Features

Even if one could use the so simply called *PDS_browser* with keyboard interaction from the Matlab prompt (one wouldn't be able to use all the features like that), this software is aimed to be used through its graphical interface so we describe in this section the different functionalities of the software from this point of view.

As one can see in Fig. 4, the graphical interface is composed of two zones to display some text, one to display a sweep curve, several clickable buttons and two fields to enter some text. The next sections are dedicated to the description of the browser.

5.1.1 User input

The user can enter either directly an existing filename (of the format seen in the data section above) or a date in the format `yyymmdd` in the larger input field and validate by hitting "input" button. Optionally, a time in the format `hh:mm` can be entered in the smaller input field before hitting input.

The search algorithm to load the requested data is very basic; it goes through an index file (loaded in memory when the program is started for the first time) required by ESA nomenclature where the data files are indexed in chronological order. Consequently, the further in time the data are, the longer the search will take; this could be easily improved by using a tad more complex algorithm like:

- go to the middle (in size for example) of the index.
- compare the date of the requested data with the date of the current position.

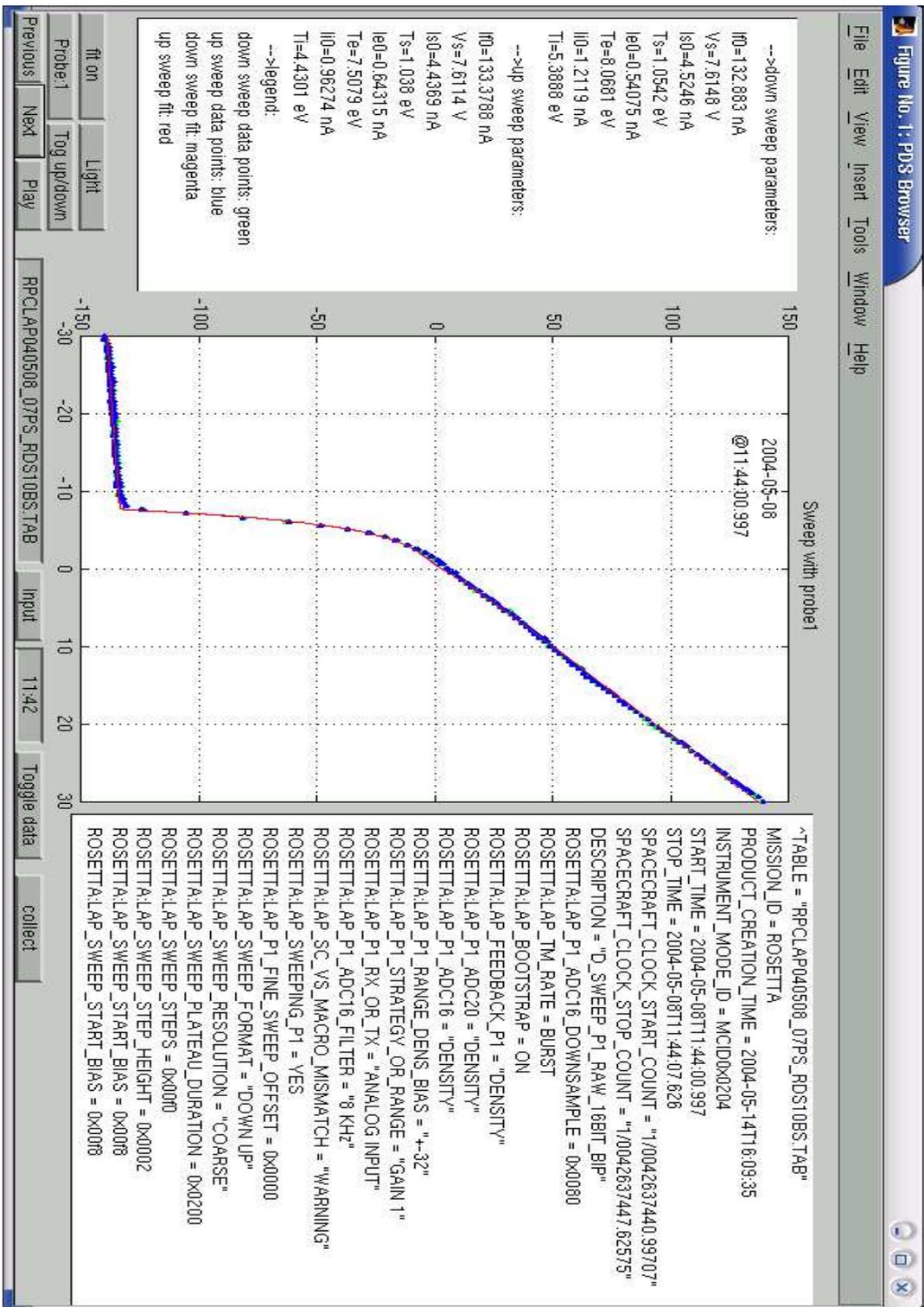


Figure 4: PDS_browser gui.

- if the first date is greater than the second (i.e the requested file is further in the index), get rid of the first half of the index, otherwise get rid of the second part.
- repeat until the requested data is found.

On the other hand, when inputting directly a filename, this one is supposed to be correct and therefore no search is made, the corresponding data are displayed immediately if existing. Note that the input only accepts a sole filename and in no case a path, the path for the data directory is hardcoded through the variable *hard_path* in `browse.m`.

5.1.2 Basic output

As seen in the previous section, a correct input entered by the user will find the requested file; subsequently, the data from the file is stored in memory to be processed in several steps. To start, some of the first data points are removed because they appear to be irrelevant (current value of -1). Then, the points are separated between the part when the bias voltage is increasing (up sweep) and the part when it's decreasing (down sweep). Next, the data, which were in telemetry units, are calibrated so that the current values are in nanoampères and the bias voltage values are in volts. Note that the parameters of this calibration are fixed and have been calculated from part of the commissioning data, this is a temporary solution while waiting for PDS files with calibrated data. Finally, the data points are displayed in a current vs bias voltage plot in the plotting area (the central one).

Additionally, the corresponding label file is also put in memory and the program goes through it to select some relevant fields which are immediately displayed in the most right text zone. It is also used to find the exact date and time of the sweep and display it in the plot area. Finally, the legend for the plot is displayed on the bottom of the most left text zone. All of this is mainly coded in `affichage.m`.

5.1.3 Fitting

In this same function `affichage` can also be called some fitting routines if requested. Those are the files in the *analysis* directory. Like any computer based solving algorithm, this fitting is highly dependent on the initial conditions because it's using a numerical approach which consists in varying the free parameters which are to be found until they fit the data the best. Consequently, the algorithm used here is only valid when the photoemission from the probe is a dominating part of the probe current around $V_B = 0$. It will thus work well in the solar wind but neither close to the Earth (or Mars) nor at the comet.

The function used to fit the data (called `lsqcurvefit`) takes in arguments: the function which is used as a model, the initial values of the free parameters, the data points which have to be fitted by the model, some constraints for the range of the free parameters, and some fitting options can be passed too.

The method used here is to fit in several stages the data by adding another contribution to the current at each stage; starting with the most important effect for the first stage and ending with the least perturbation for the last stage.

The first stage uses only the current created by the photoemission from the probe itself because

it is by far the most important effect (only when the probe is in sunlight). The equation used for this model are equ. (11) and (12) with I_{f0} and V_s as free parameters and T_{p0} fixed to 2 eV.

The second stage uses I_{f0} and V_s which have just been found by the first stage and adds the current due to the photoemission from the spacecraft. The equation added are equ. (13) and (14) with I_{s0} and T_s as free parameters.

The third stage let I_{s0} and T_s be free parameters again and adds the model for the electrons from the solar wind. The new equations are (7) and (9) with I_{e0} and T_e as third and fourth free parameters. Originally, I_{s0} and T_s were fixed in this stage, using the values found in stage 2, but it appeared the fitting is more precise if those 4 parameters are kept free altogether. This finally makes stage 2 completely useless, it should therefore be removed in later implementations because it is just unnecessary calculations.

The fourth step adds the last contribution in this model, ie the solar wind ions, by adding equations (8) and (10). The new free parameters are I_{io} and T_i , and all previous parameters are fixed using the values found in the previous stages except for I_{f0} which is set free again in order to let the slope of the curve free for $V_p < 0$.

Finally, a last stage is computed which all the previous current contributions and with all parameters free (I_{f0} , I_{s0} , I_{e0} , I_{io} , T_s , T_e , T_i). However, the values found in the previous stages are used to set some tight constraints on this fit to insure that the fit function will find the right results (since it's a minimum search, several results could be possible for each free parameter) and also to avoid some useless and time consuming calculations. Hence, after this last step, eight parameters to fit the data have been computed and are stored in memory for further use.

5.1.4 Additional controls and features

This software was intended to easily browse the LAP data files that's why some other features have been implemented.

For starters, one can notice the “next” and “previous” buttons which allow to quickly go forwards and backwards in chronological order through the files. All the actions which were executed on a call for `input` function are also executed on a click on “next” or “previous”; i.e up/down separation, calibration and displaying of the graph and the information texts. The execution is of course way faster than with the use of “input” because no search is made, the next (resp previous) file in chronological order relatively to the one which is currently displayed is simply picked up in the directory where the data files are, the index file is not used here.

The “play” button calls a simple routine which executes the `next` function at a regular time interval (which can be changed in `play.m` file, the default is 0.15 seconds) as long as the “play” button is not pressed a second time.

The “toggle probe” button allows to process only the data from LAP1, or only LAP2, or both of them as it is the default case. For example, if the button is pressed once, only probe1 is enabled and the program will ignore the files containing data points from Rosetta Langmuir probe 2. This is useful for instance in the case when one of the two probes is in the shadow created by the spacecraft (which was the situation during commissioning) and you want to observe only the behavior of the probe in sunlight.

The “Tog up/down” button allows to choose wether to treat only the up sweep (resp down sweep) or both of them (by default). If only up (resp down) is selected, all the operations related

to the other part are skipped so the execution should be almost twice faster.

The “fit on/off” button obviously permits to enable or not the fit of the data. It is worth to let it off if the fit is not wanted since the execution is a lot faster if the fits are not computed. If enabled, the fits are computed, the fit curves are displayed in the graph zone (magenta for down sweep and red for up sweep by default), and the resulting fit parameters are displayed in the most left text zone.

The “collect” button enables to save the computed fit parameters in a file. When pressed once, it (creates if necessary and) opens in write mode a file named `lap_data.txt` in the parent directory of the LAP data directory (this can be changed in `collect.m`) and close this file if pressed a second time. When the file is open, and if the fit is enabled (with “fit on/off” button), the parameters are simply appended to the file each time a fit is computed. There is no verification if some parameters have already been written, so if one for example uses a sequence like next, previous, next, the same parameters will be written twice in the file. Also note that some of the files are automatically excluded (by checking at the instrument mode ID field in the label file) because they were of no interest for the physical analysis.

The “Toggle data” button should be operational though it is of no use for the moment; it permits to switch between data from CALIBRATED, DERIVED, and EDITED directories (default EDITED) in the DATA directory of the LAP data directory.

Finally, the “Light/Shadow” button is supposed to switch between a model where the probe is in sunlight or in the shadow of the spacecraft but it’s not operational at the moment because the models for the shadow are not implemented.

6 Results

Before talking about any science analysis, it is interesting to note that the browsing software appeared to be quite convenient to go quickly through all the generated data and detect by this means errors in the database such as duplicate files, wrong chronological order or unexpected gaps in the pool. Because Rosetta mission involves a lot of instruments and teams all around the world, the resulting conventions for the creation of the data archives from the raw data are somehow complicated and can easily be subjects to errors and misunderstandings. It is thus useful to have a tool which can relatively quickly go through all the data (or investigate at a precise point in time) while providing a convenient way to monitor the time of the measurement, the instrument mode ID, and of course the data points themselves. That’s why this software is appropriate for this kind of task and could probably be enhanced for this purpose in the future.

For the science objectives it was rather easy to acquire all the interesting sweeps once the browser was finished. The processus was almost fully automatic thanks to the `play` function; and the sweeps in shadow were avoided simply by enabling only the LAP1 probe since all the LAP2 bias sweeps were in shadow. As said in the above section, the “non interesting” (ie non bias voltage sweeps in sunlight) sweeps were also not written in the file thanks to a detection with instrument mode ID. All the fit parameters were printed in a file, ordered by columns and hence easily usable with Matlab to make some plots. A simple routine hence allowed to obtain the following plots for both up and down sweeps:

- $V_s, T_s, T_e, T_i, I_{f0}, I_{s0}, I_{e0}$ and I_{i0} against time.

- $T_s, T_e, T_i, I_{f0}, I_{s0}, I_{e0}$ and I_{i0} against V_s .
- The electron density measured by the ACE spacecraft (found at <http://sec.noaa.gov/ftpmenu/lists/ace.html>) n_e against V_s .

All those plots can be found in Figures 5, 6, 7, 8 and 9 where the green points are for the down sweep parameters and the blue points are for the up sweep ones. Note that T_e vs V_s has been plotted with a maximum value of 15 eV for T_e while a few points were higher than 15 eV so they don't appear on the plot.

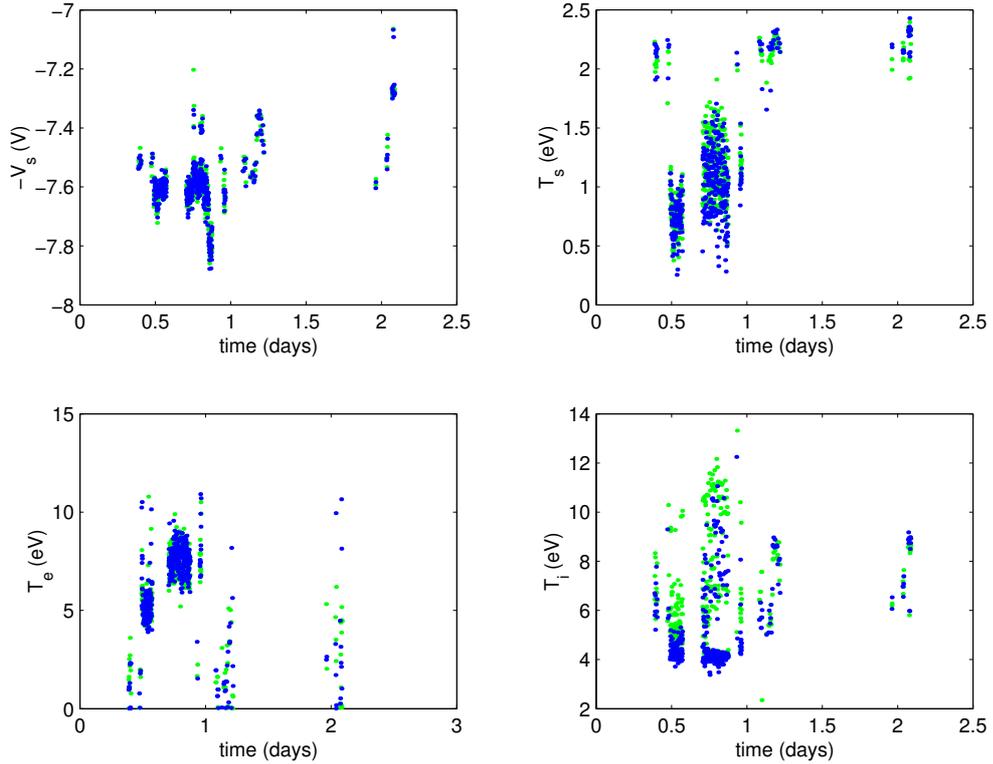


Figure 5: $V_s, T_s, T_e,$ and T_i against time.

Which source of plasma that dominates the probe current will depend on where on the probe curve we look. However, one way of establishing the relative importance of the different current sources listed in section 3.4 is to look at the characteristic values I_{f0}, I_{s0}, I_{e0} and I_{i0} . From Fig. 6, we find that the dominating current in this sense is the photoemission, as the typical value of the photoemission saturation current I_{f0} , around 130 nA, is more than 10 times higher than any of the other terms. This is exactly as expected for the solar wind plasma.

Among the remaining current sources, the photoelectron cloud from the satellite is the largest in the sense that the typical I_{s0} values, some 2 – 10 nA, is the next in order of magnitude. This is not strange: in the tenuous solar wind plasma, the density of photoelectrons is likely to dominate over the natural plasma electrons at the location of the probe.

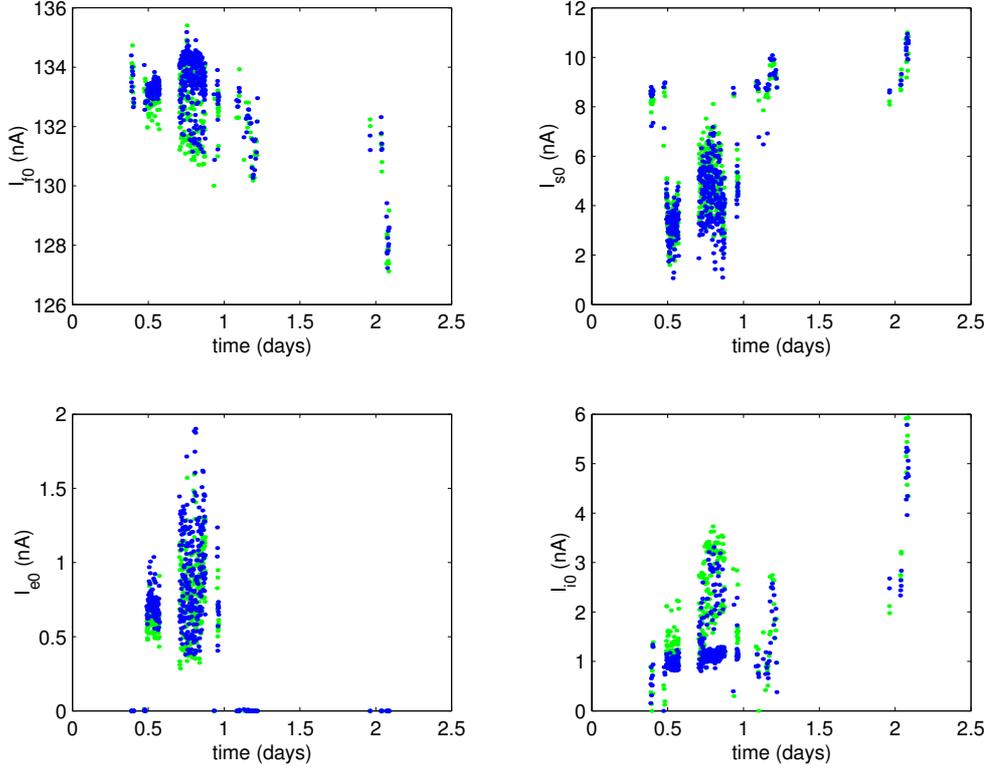


Figure 6: I_{f0} , I_{s0} , I_{e0} , and I_{i0} against time.

Can we at all measure the plasma electrons in this situation, when the photoelectron density probably is much higher than the density of natural plasma electrons near the probe? From equation (6), it follows that expected values of I_{e0} for a solar wind with density 2 cm^{-3} (typical for these days according to the ACE data in Fig. 9) and electron temperature of 12 eV (140,000 K, typical value from Table 1) is around 1.5 nA for the LAP probes of radius 25 mm. The values we find for I_{e0} in the plots is exactly of this order. This could be a numerical coincidence, but looking at the temperature plots in Fig. 5, we also find values of 5 – 10 eV for T_e , while T_s stays much lower. This is the expected order of magnitudes for solar wind electrons and the photoelectron cloud (see Ref. [5]) respectively, so it is possible that the fitting algorithm indeed is capable of picking up the small trace of plasma electrons.

To further investigate if this is the case, we look for correlations between I_{e0} and the spacecraft potential V_s in Fig. 7. As shown in for example Ref. [5], V_s must anticorrelate with the plasma density in a tenuous plasma. This is simple to understand: the fewer plasma electrons there are to collect, the more of its own photoelectrons must the spacecraft drag back in order to keep the net current zero, which means it must go to higher potential. If the I_{e0} values we derive from the sweep are real they should be proportional to the density, and hence V_s and I_{e0} should anticorrelate. There is almost no hint of any such behaviour in Fig. 7, but on the other hand the variations in V_s seen during the days of operation are rather small, well within 1 V, so the noise

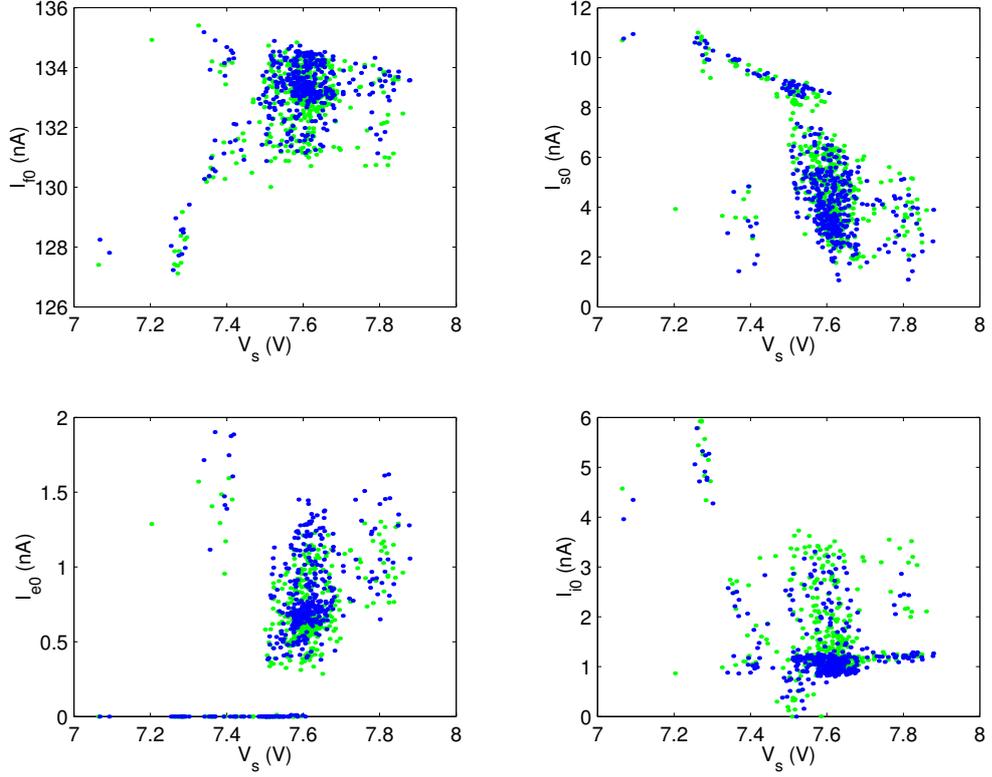


Figure 7: I_{f0} , I_{s0} , I_{e0} , and I_{i0} against V_s .

in the I_{e0} estimate may swamp any real correlation.

A stronger hint of anticorrelation with V_s is seen for I_{s0} , the current collected from the photoelectron cloud. This can be understood in terms of a higher V_s value keeping the photoelectrons closer to the spacecraft, so that fewer can reach the probe.

The ion current behaves somewhat strangely. The value of I_{i0} is higher than I_{e0} which is not expected, as the electrons are lighter and more mobile. While the derived T_i values indeed may seem to be of the correct order of magnitude (compare to Table 1), this is unexpected as T_i here rather should represent the solar wind ion drift energy, around or above 1 keV (see discussion following equation (10)). It is possible that there is some instrument offset not yet corrected for that causes this behaviour, whose origin is the fact that the probe curve (see the example in Fig. 4) deviates from being perfectly horizontal more than expected at negative voltages. This will need further investigations.

Hence, it is still uncertain if any parameters of the solar wind can be derived from the current and temperature values obtained by the probe sweeps in the very tenuous solar wind that surrounded Rosetta during the days of operation. This is entirely as expected: LAP is designed for much denser plasmas. However, two of the fit parameters are very reliably determined, given that they alone dominate the shape of the probe sweep: the spacecraft potential V_s , which just is the position of the knee on the curve, and the photoemission saturation current I_{f0} . Fig. 6 sug-

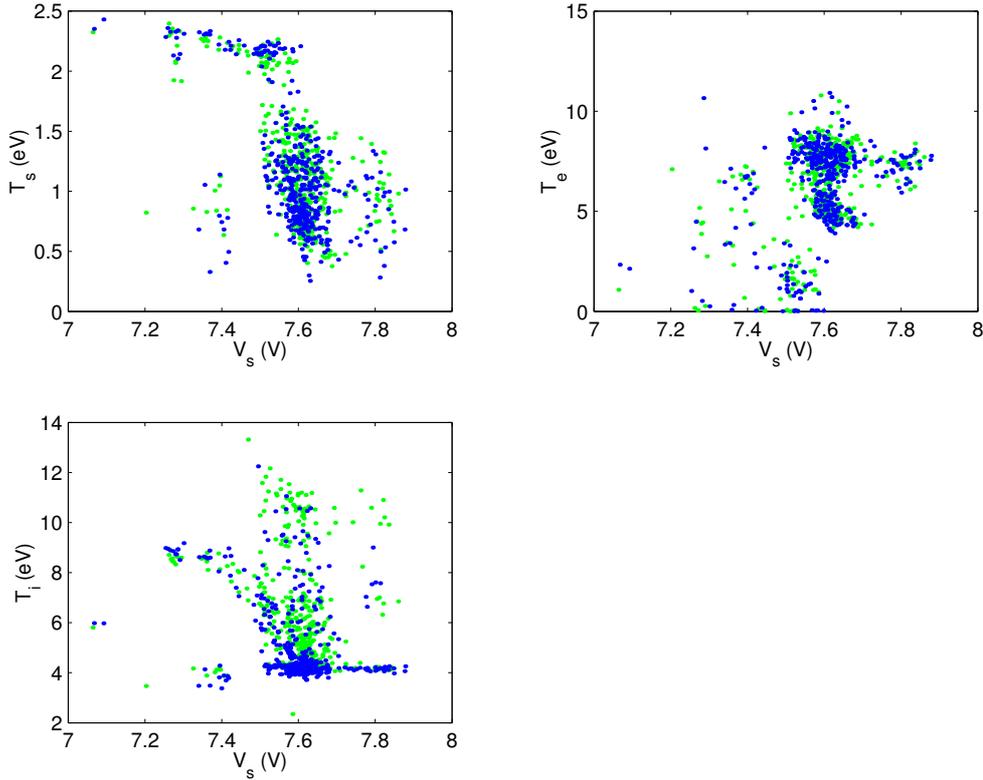


Figure 8: T_s , T_e , and T_i against V_s .

gest that I_{f0} may have a decreasing trend during the days of operations, which could possibly reflect a variation in solar UV intensity. This has not been possible to check within this project, but would be of interest to follow up in further studies.

That the spacecraft potential is accurately determined can be seen also from the fact that the values from the up- and downward portions of the sweeps are almost identical (Fig. 5). As we discussed above, V_s must depend on the plasma density, as has been experimentally verified on many spacecraft (see also Ref. [5]). We have no independent density measurement to compare to on Rosetta, but we can compare our V_s data to density measurements made simultaneously by some other spacecraft. In Fig. 9, we have plotted our V_s data versus the plasma density obtained from the ion detectors on the ACE spacecraft, situated at the L1 Lagrange point between the sun and the Earth (but much closer to Earth). It is not possible to see any clear correlation. However, ACE and Rosetta are rather far from each other, as can be seen in Fig. 10. We should therefore not be surprised over the lack of correlation – it simply shows that the main density structures in the solar wind are not coherent over the distance separating Rosetta and ACE during this time.

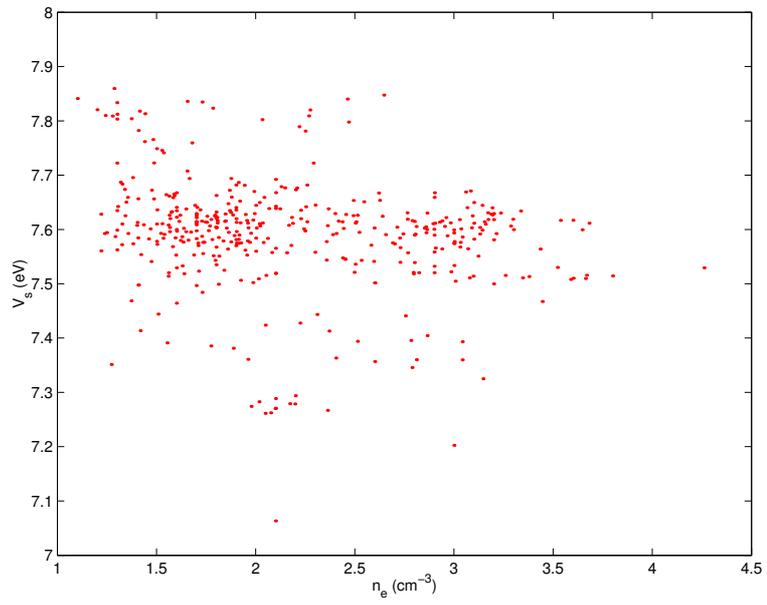


Figure 9: V_s against the electron density measured by Ace.



Figure 10: Rosetta position.

7 Conclusion

In the end, we can say we achieved quite satisfactory results: as a first point we now have a working tool to investigate on the integrity and completeness of the data and on a second point we have been able to judge of the high quality of the instrument resolution. Of course, there still are some doubts about the values obtained for certain parameters, such as the ion current, and an improvement of the model used in the algorithms as well as an investigation of the possible offsets to recalibrate will probably be the key to fully determine the reliability of such measurements. However, it is quite impressive to have obtained such realistic values for most of them whereas the instrument is designed to operate in an environment of much higher density; this let us expect some really good results for the measurements to come, i.e in Mars ionosphere and of course in the comet vicinity.

8 Acknowledgements

I would like first to thank everyone of the Space Physics Institute for their warm welcome and their kindness with me, it was very nice working in this friendly environment. Then I'd like to say thank you to all the PhD students for these nice talks and the football games, thanks to Roger for his help with \LaTeX and to Bertil for his advices and talks about computer stuff.

And finally, I'm really grateful to Reine for all his help during this work and of course this project wouldn't have been possible without Anders; so thanks a lot to him for the time he took to help me, for his non negligible contribution to this document especially in the part on the results, and above everything for giving me the opportunity to prove I could do some serious (albeit short) work on a research subject.

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A Appendix

All the following code can be freely reused as long as it is for non-commercial use. Note: there seem to be a conflict in more recent Matlab versions (this code was written with version 6.0.0.88) because of a new function also called *fit*; this should be corrected in the last version of *PDS_browser*.

Note: Appendix not included in this PDF version.