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Preliminary report of the analysis and visualisation software for SMART-1 SPEDE and EPDP instruments

SINI MERIKALLIO

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PRELIMINARY REPORT OF THE ANALYSIS AND VISUALISATION SOFTWARE FOR SMART-1 SPEDE AND EPDP INSTRUMENTS

Sini Merikallio

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Analysointi ja visualisointi ohjelmisto SMART-1 satelliitin SPEDE ja EPDP instrumenteille, alustava raportti

Tiivistelmä

SMART-1 oli Euroopan ensimmäinen kuusatelliitti. Tämä pieni (1 m³ ja 366,5 kg) satelliitti laukaistiin Kourousta syyskuussa 2003. Se saavutti Kuun kiertoradan maaliskuussa 2005. SMART-1:n taival päättyi suunnitellulla törmäyttämisellä Kuun pintaan syyskuussa 2006. Dataa sen instrumenteista saatiin pian laukaisun jälkeen aina lennon viime sekunneille asti.

SMART-1 oli ensimmäinen sähköelektristä propulsiota käyttänyt Eurooppalainen satelliitti. Tämän propulsiotekniikan testaus ja verifiointi olivat sen mission päätehtäviä. Kaksi instrumenttia, SPEDE ja EPDP, monitoroivat satelliitin plasmaympäristöä ja siten myös moottorin ionisuihkun käyttäytymistä ja sen vaikutusta aluksen varautumiseen. SPEDE suoritti mittauksia myös kun moottori oli poissa päältä. Tällä missiolla kerättyä dataa käytetään sähköelektrisen propulsion käyttökelpoisuuden arvioimiseen ja mallinnustyökalujen validointiin.

SMART-1:llä on kolmea Langmuir instrumenttia. Kaksi näistä muodostaa SPEDE instrumentin ja kolmas on osa EPDP pakettia. Langmuir anturit ovat hämäävän yksinkertaisia johtavia puikkoja jotka asetetaan plasmaan, jolloin ne ovat vuorovaikutuksessa ympäröivien ionien ja elektronien kanssa. Kun tällaisen puikon jännitettä muutetaan, muuttuu myös siitä mitattava virta. Tuloksena syntyvästä jännite-virta kuvaajasta voidaan johtaa hyvin monia plasman ominaisuuksia, kuten elektroni-lämpötila ja tiheys, satelliitin kelluva potentiaali ja ioni tiheys. Näiden suurteiden tunteminen on edellytys plasman käyttäytymisen syvempään ymmärtämiseen.

Tässä raportissa kuvataan SPEDE ja EPDP datan analysointiin ja visualisointiin tuotettu ohjelma ja sen käyttö. Myös alustavaa analyysiä SPEDE datasta on liitetty mukaan. Tämä toimii samalla ko. datasetin esittelynä.

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Abstract

SMART-1 (Small Missions for Advanced Research in Technology) was the first European moon satellite. This small (1 m³ and 366.5 kg) satellite was launched from Kourou on Ariane 5 in 27th of September 2003 and started to produce data shortly afterwards. SMART-1 slowly but surely reached its Moon orbit on March 15, 2005. The SMART-1 mission then got an extension and produced data until beginning of September 2006 when it was impacted on the surface of Moon as planned.

SMART-1 was the first European satellite using Solar Electric Propulsion as its primary propulsion system. One of its main tasks was to verify and test this energy efficient technology that is also going to be used on larger scale future missions like Bepi-Colombo. Electricity is produced by solar panels that span 14 meters.

Two instruments, the Electric Propulsion diagnostic Package (EPDP) and the Spacecraft Potential, Electric fields and Dust Experiment (SPEDE) monitored the thruster plume interaction effects. SPEDE also measured ambient plasma when Electric Propulsion (EP) was turned off. The data collected in this flight experiment is used not only to assess the impact of using electric propulsion on board scientific satellites but furthermore to validate modeling tools which will be employed in a full characterization of the impact of using this technology in space.

There are three Langmuir probes on SMART-1. Two of these form the SPEDE instrument and one is part of the EPDP instrument package. Langmuir probes are deceitfully simple electronic probes inserted into plasma. When their electronic potential is varied, the amount of current collected from the surrounding plasma also changes. From the resulting data, a great deal of information about plasma can be extracted, such as the electron temperature and density, floating potential, and ion densities. This information can be incorporated into models to derive a more complete picture of the plasma environment.

In this report software is described to be used for SPEDE and EPDP data handling and analysis, focus being on the Langmuir probe data. Preliminary analysis of the early SPEDE data is also included.

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Symbols and Abbreviations

$ESTEC$	European Space Research and Technology Centre
ESA	European Space Agency
$SPEDE$	Spacecraft Potential, Electron and Dust Experiment
$SMART$	Small Missions for Advanced Research and Technology
$EPDP$	Electric Propulsion Diagnostic Package
EP	Electric Propulsion
RPA	EPDP Retarding Potential Analyzer
QCM	EPDP Quartz-Crystal Micro-balance
LP	Langmuir Probe
SC	Solar Cell
EF	Electric Field
HK	House Keeping
PD	Plasma Diagnostics
CEX	Charge Exchange
FMI	Finnish Meteorological Institute
AVA	Space Research Department of FMI
g	gravitational acceleration
HUT	Helsinki University of Technology
λ	wavelength
LCE	Laboratory of Computational Engineering, HUT
LT	local solar time
$\parallel$	parallel, (also 'l')
$\perp$	perpendicular, (also 'r')
q	charge
Re	Earth radius
T	temperature
U	potential

Chapter 1

Introduction

SMART-1 (Small Missions for Advanced Research in Technology) is the first European moon satellite. This small (1 m^3 and 366.5 kg) satellite was launched from Kourou on Ariane 5 in 27th of September 2003 and started to produce data shortly afterwards. SMART-1 slowly but surely reached its Moon orbit on March 15, 2005. The SMART-1 mission then got an extension and produced data until beginning of September 2006 when it was impacted on the surface of Moon as planned.

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There are three Langmuir probes on SMART-1. Two of these form the

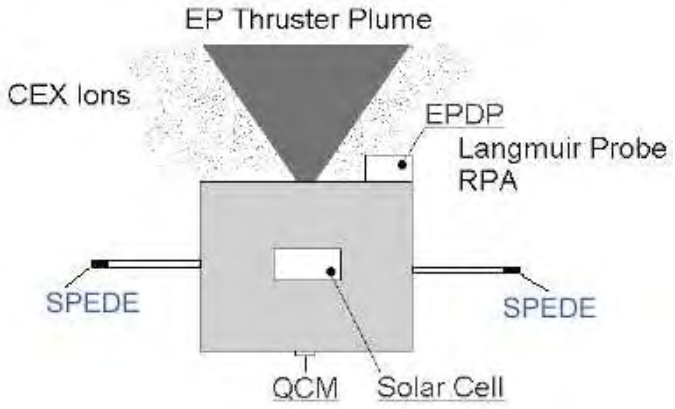


Figure 1.1: Schematic drawing showing the relative positions of SPEDE booms, EPDP instruments (LP, RPA, QCM and Solar Cell) and EP ion plume. Also shown are charge exchange ion cloud.

SPEDE instrument and one is part of the the EPDP instrument package. Their relative locations can be seen in figure 1.1. Langmuir probes are deceitfully simple electronic probes inserted into plasma. When their electronic potential is varied, the amount of current collected from the surrounding plasma also changes. From the resulting data, a great deal of information about plasma can be extracted, such as the electron temperature and density, floating potential, and ion densities. This information can be incorporated into models to derive a more complete picture of the plasma environment.

In this report a software is described to be used for SPEDE and EPDP data handling and analysis, focus being on the Langmuir probe data. Preliminary analysis of the early SPEDE data is also included.

1.1 SPEDE

The SPEDE instrument is optimized to monitor the spacecraft's plasma environment using as little mass and power resources as possible. It consists of two short sensor booms, Boom +X and Boom -X, mounted at opposite sides of the spacecraft (see figure 1.1), and a small electronics box inside the spacecraft's warm compartment with power converter and instrument control electronics. [Ins05]



Figure 1.2: SPEDE boom 1 being integrated on +X panel. The other SPEDE boom is located on the opposite side of the spacecraft. Image is courtesy of Finnish Meteorological Institute.

Both SPEDE sensors can be used to monitor the potential difference between one sensor (current-biased) and the spacecraft, or (voltage-biased) to measure the electron flux. SPEDE electronics were built by Finnish industry, while the sensor structure and power converter is contributions of the Co-I groups at ESTEC and at Uppsala group of the Swedish institute for Space Physics. [Ins05]

The Planetary Research group at the Finnish Meteorological Institute (FMI) as Principal Investigator has the main responsibility for the SPEDE instrument, its development, integration, testing and operation. The complete electronics with its new technology concepts is designed and manufactured in Finland. Additionally the group at FMI is directly responsible for the flight software development and the analysis of the gathered data. [Ins05]

The SPEDE instrument paper discusses the capabilities of SPEDE in more detail [AM04].

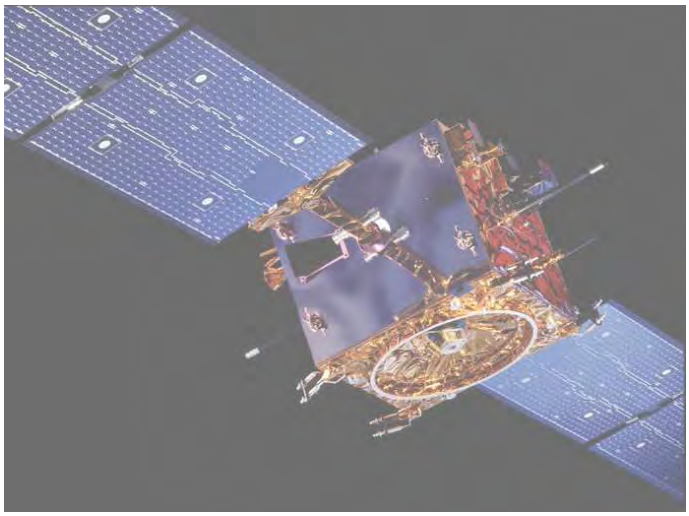


Figure 1.3: SMART-1 body showing SPEDE booms on opposite sides of the satellite and the electron propulsion engine in the lower right panel.

1.2 EPDP

Electric Propulsion diagnostic Package (EPDP) has many interesting experiments. There are the Langmuir Probe (LP), the Retarding Potential Analyzer (RPA), the Quartz-Crystal-Microbalance (QCM) and the Solar Cell (SC) experiments. The program described in this paper has capabilities on reading, plotting and doing some analysis on data products of all of these instruments.

The priority in this document has however been given to the SPEDE data and thus only a few plots of EPDP data have been shown. Further information on EPDP data products can be read in EPDP Flight Data Report [CS05].

Chapter 2

Program description

A software was developed to effortlessly read, handle and analyze the SPEDE data. In order to validate and compare SPEDE data with other instruments on SMART-1, capability to analyze EPDP measurements was added. It would also be relatively easy and straightforward to add data from any other instrument if there would be need for that. The user interface and modular structure could also be used for other missions and datasets with relatively little tuning. In this document the emphasis is on familiarizing any potential users with the software rather than going through the code in detail. Theory behind Langmuir probes and explanations of the analysis methods used in this software are more thoroughly explained in literature [L.83a, L.83b, Stv04, AF73, MS05] and in a parallel Demeter data plotting software documentation [Mer06].

The program package described in this work was developed and tested in ESTEC between August 2004 and July 2005. It has been written on Unix Matlab R14 and might not work as expected on older versions of Matlab or on Octave. Neither has it been tested on Windows or Linux environments and might need some changes to properly work on those environments. IDL is used to run SPICE libraries to acquire the planetary ephemeris and orbital data (see appendix C). Later some features were added and bugs corrected at Finnish Meteorological Institute (FMI) during the winter 2005/2006.

In this chapter we first go through the essential things required to run the program (section 2.1). After making couple of comments of the program struc-

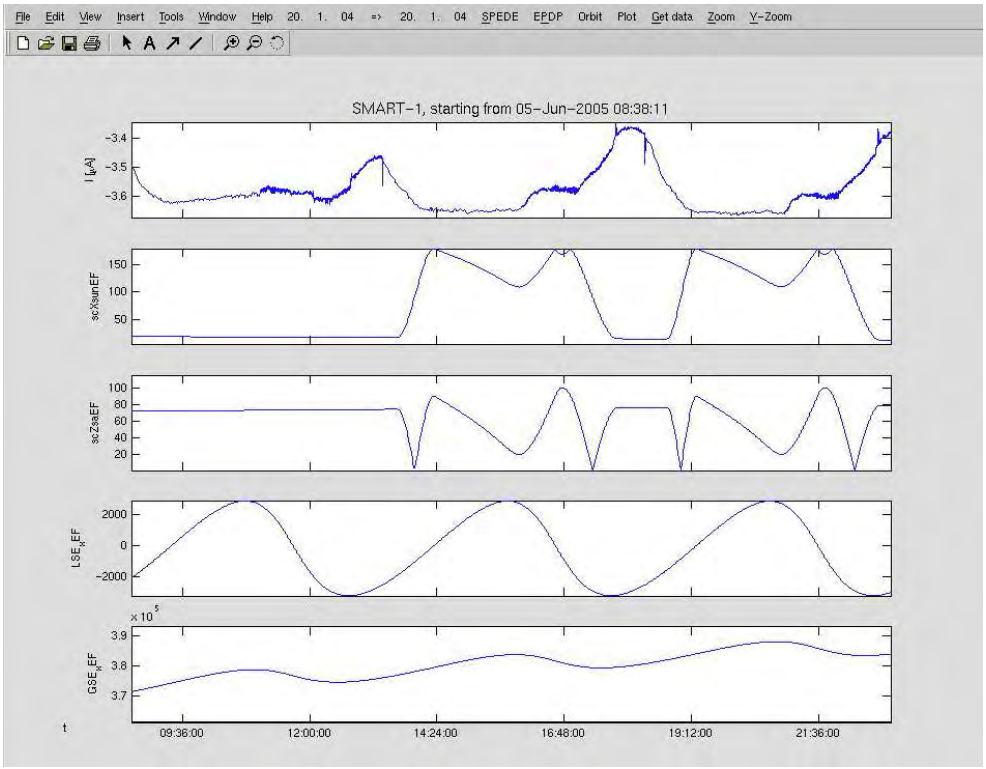


Figure 2.1: User interface of the program. All the top menus are shown and some data has been retrieved and an image plotted. Shown here are the Langmuir Probe current, spacecrafts X-axis angle with respect to the Sun, spacecrafts Z-axis angle with respect to. solar arrays and also LSE and GSE x-coordinates (distance from Moon and Earth).

ture (section 2.2), a look is taken at the user interface and its most important features in section 2.3.

2.1 Before Starting

The program starts by running the 'spede2' script from the SPEDE folder. Before running it though, you should change three paths at the beginning of the spede2.m script to tell the program where your EPDP, SPEDE and Kp-index data resides. By default these paths have values:

```
polku_EPDP ='/data/smerikal/EPDP/'
polku_SPEDE ='/usr4/users/smerikal/SPEDE/'
polku_Kp = '/usr4/users/smerikal/SPEDE/'
```

polku_EPDP points to the folder where the EPDP data folder '2004_08b' is. When this data set is changed to a newer one, the pathnames have to be updated in all EPDPread***.m files. polku_SPEDE is the folder containing these subfolders:

```
S1-X-SPEDE-2-EDR-BKGRPLASMA-V1.0
S1-X-SPEDE-2-EDR-EP-MONITORING-V1.0
S1-X-SPEDE-2-EDR-LEOP-CALIBRATION-V1.0
S1-X-SPEDE-4-REFDR-BKGRPLASMA-V1.0
S1-X-SPEDE-4-REFDR-EP-MONITORING-V1.0
S1-X-SPEDE-4-REFDR-LEOP-CALIBRATION-V1.0
```

When paths are set up correctly, the program can be started by running spede2.m. To run the program from a different folder, one can command

>run('path/SPEDE/spede2.m').

In figure 2.1 a screenshot of the SPEDE tool is shown. At first run the figure is empty and only the menus differ from default Matlab figure.

2.2 Structure

Program M-files are listed in Appendix A. Data is read with SPEDEreadDATA routine and saved into .mat files named after the start and end dates of data retrieval. Workspace filenames might be *Spede_MO*_040120_040120.*mat* or *Spede_BG*_040101_040231.*mat*. In the middle of the name there is also a folder abbreviation citing the folder where the latest bits of data of this workspace came from. Abbreviations used are 'CA' for 'CALIBRATION', 'MO' for 'MONITORING' folders and 'BG' for 'BKGRPLASM' folder (see folder listings in section 2.1 and the science archive interface control document for more information on mission delivered data structure [Gen04]).

The SPEDEreadDATA reads all the available data, preprocesses and saves it. For all the different data there are separate reading functions or scripts to acquire the data from desired time span. For EPDP and SPEDE data the reading functions are coping with one day of data at a time and thus are run

inside a time loop in SPEDEreadDATA. Some data like Kp-index on the other hand is all in one file and is read and chopped as needed.

An ample amount of different functions and routines have been developed around the data structures to help in analyzing and plotting the data. The main purpose of this document is to introduce users of these data sets to the possibilities of the program developed in this work.

There is no common matrix or time grid for data but instead for all the data also a time vector (usually something starting with letters 'UTC') is saved. When values of some data is needed in a certain point usually a linear approximation is made between the nearest two data points. For example in cases of multiple x-axis this needs to be done. Time vectors of data are usually so dense and the rate of data change so low that this produces a more than good enough accuracy, which is the case with orbital data for example.

2.3 User Interface

2.3.1 Overall Description

User interface is done in the format of a Matlab figure with couple of application specific additional menus. The program is started with the command 'spede2' which opens a figure and names it 'SPEDE'. To run spede2 from another directory, type: run('path/spede2'), where path shows the way to the SPEDE folder. A 'Soutput' directory will be created in the folder the program is started from. All output of the program will as default be saved there. If the 'Soutput' directory already exists, it will be used as a default save-directory and its previous content will be left untouched as long as the filenames differ with the ones that will be created with the program. If one wishes to save all the runs after a day's work, perhaps the easiest thing to do is to change the name of the 'Soutput' folder into something else, for example with some datetag like 'Soutput_Dec_03'.

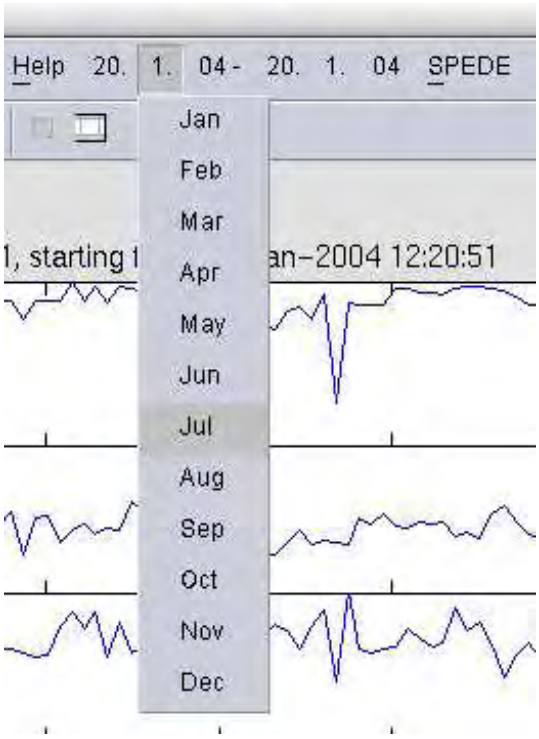


Figure 2.2: Menu to choose the starting month of data retrieval span. Menus for dates and years are comparative.

2.3.2 Menus

The time span for data reading is handled with the first six menus. First in the row are the starting day, month and year after which the equivalent ending times. 'SPEDE' and 'EPDP' menus include different datasets that are ready to be used in plotting. In addition to holding only SPEDE and EPDP instrument data, also electronic propulsion power data, Kp-index and orbital data are included. The 'Plot' menu holds different plotting commands, including dayplots and sweep plots as well as commands to clear or hold on to figure. 'Get Data' offers two choices, it either initiates the data reading or gives a dialogue to load old workspace from file. 'Zoom' doesn't have any sub-menus. In this section we take a better look at all the menus.

Start and Stop Time

First six menus are used to tell the program the time span from which the data is to be read and processed. From these drop menus it is straightforward to choose the starting day, month and year (three first menus) and the stopping day, month and year respectively. If the stop time is set earlier than the beginning time, no error will occur but the processing will go on and corresponding orbital data will be saved.

One day of data produces typically a .mat file of about 10 Mb. Some status indicators are not read or saved because of their huge memory consumption (strings). But corresponding lines from the code can be uncommented if need be and there is enough memory available. A half a year worth of data is still manageable but very heavy on analysis. It has to be noted though that many data types are saved as monthly chunks and thus take as much space if read for a day or for four weeks. To keep the load on the system moderate, it is advisable to keep the time spans on strips of less than one month. Very often availability of memory limits the maximum sensible time span to few days. Care also has to be taken here, as a failure to change the years with other dates can result in very heavy data retrievals of more than one year. When this happens, interrupt the data call with Ctr+C, set the correct times and restart retrieval.

SPEDE and EPDP menus

From SPEDE and EPDP menus one chooses the desired data to be plotted. The SPEDE menu, figure 2.3.2 holds reference voltages, temperatures and some SPEDE related measured as well as derived quantities. In the EPDP menu one can, besides EPDP data products, also find the Electric Propulsion Power (figure 2.3.2). Division of variables in menus can easily be edited by moving these menu-elements around in spede2.m. Available data items are colored blue whereas menu items pointing to non-existent data are shown in black.

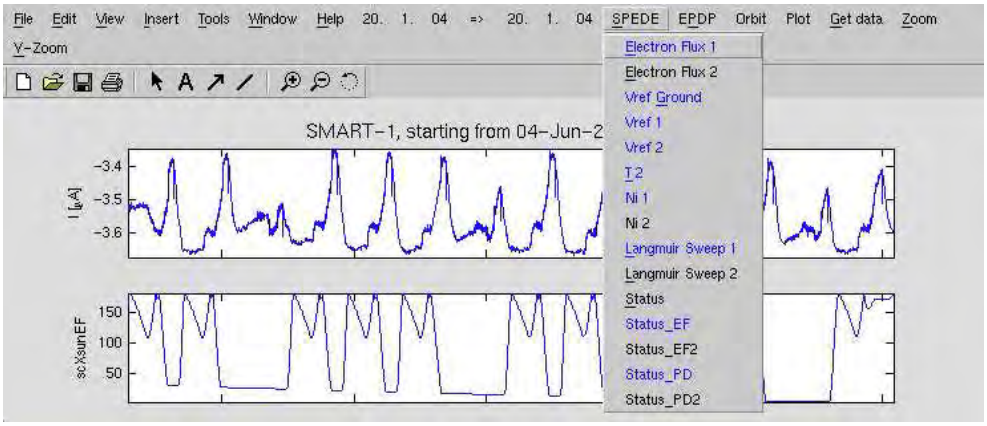


Figure 2.3: SPEDE menu. Available data items have been colored blue; SPEDE probe-2 has not been making any measurements during the time span that has been loaded to the workspace.

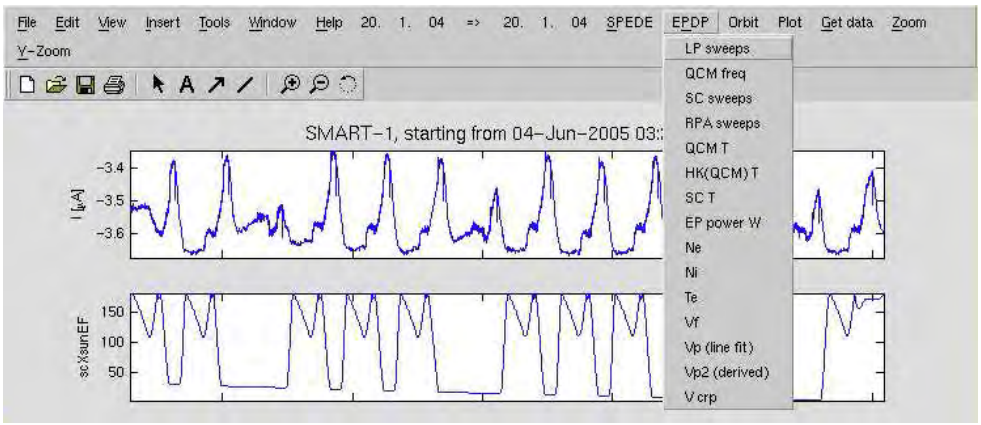


Figure 2.4: EPDP menu. Available data items have been colored blue; seems that all of the EPDP data is available in the case of this screenshot.

Orbit menu

Final version of SPEDE dataset will also include GSE (Geocentric Solar Ecliptic) and LSE (Lunar-centric Solar Ecliptic) coordinates as well as various angles fixing the orientation of the spacecraft and its solar panels.

Orbit menu is an extension to SPEDE and EPDP menus, holding other data items mainly concentrating on orbital data. In addition to GSE and LSE coordinates also shadow bit and Lt index are presented as well as several angles describing spacecraft and its solar panels position. In Earth centered GSE coordinates the X-axis points from Earth to the Sun and the Z-axis points

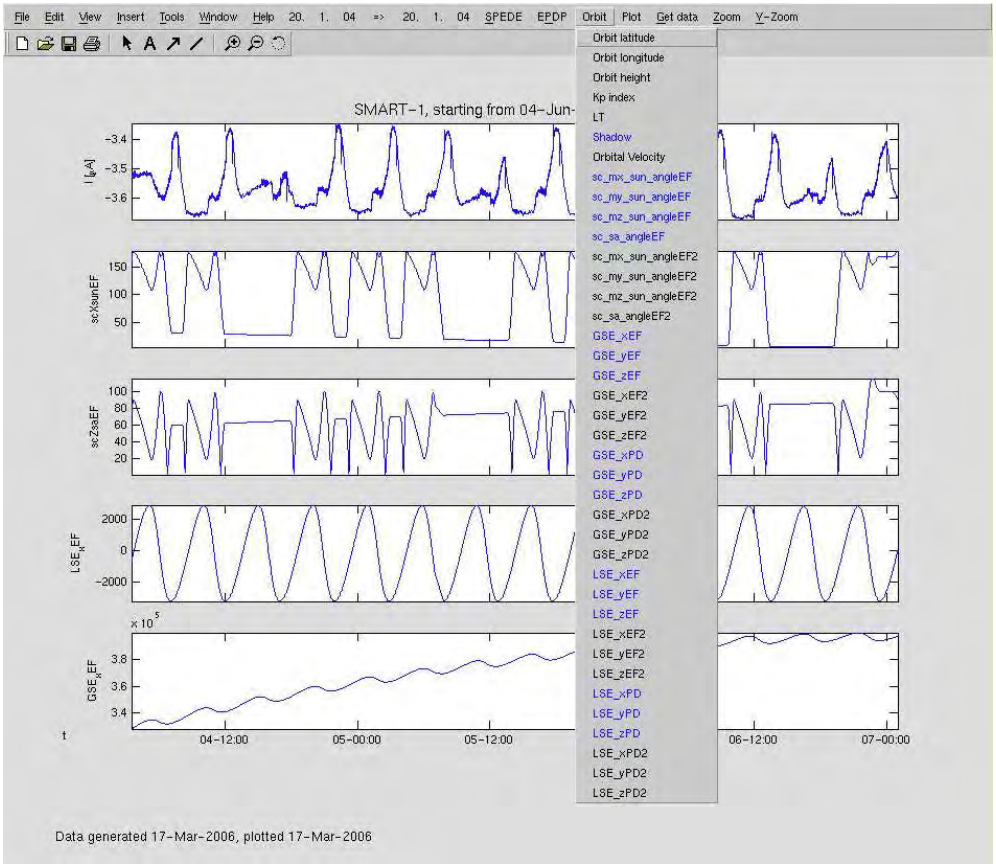


Figure 2.5: Orbit menu functions in similar fashion to other menus offering various orbital parameters for plotting.

to the ecliptic north pole with Y-axis complementing the right-handed triad being roughly antiparallel to the Earth's orbital velocity. In LSE the origo has been changed from the center of the Earth to the center of the Moon, but direction vectors are defined in the same way as in GSE.

Most of the menu items end with 'PD', 'PD2', 'EF', or 'EF2'. These indicate from which dataset the data is collected. For example in figure 2.3.2 only data from the first boom, marked with 'EF' and 'PD' has been collected and are shown in blue. The 'EF' marked data is recorded in connection, and thus in the same frequency, with the Electric Field measurements whereas 'PD' tagged data follows Plasma Diagnostics frequency.

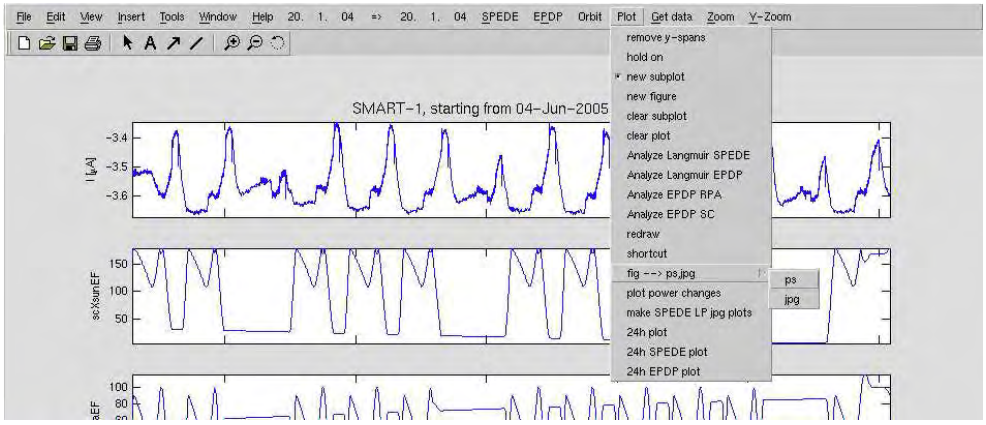


Figure 2.6: PLOT menu.

Plot menu

In PLOT menu the user can find some tools to edit the current plot (see figure 2.3.2 and section 2.3.4) and all the automated plotting routine commands (see section 2.3.6). The 'redraw' choice makes the plot anew. This is handy after changing the 'shortcut' (sec. 2.3.5) or when a adjustation of the axis is desired. A plot can be saved by choosing 'fig –> ps, jpg' and inputing the desired filename on the appearing dialog box. To view sweep formed data one can choose between different 'Analyze' scripts, also found under the plotting menu and further discussed in section 2.3.7.

Get data menu

There are two possibilities to get data into the program. These can most conveniently be accessed through the 'Get Data' menu shown in figure 2.3.2. Either one reads the data from separate files according to the chosen time span, see section 2.3.2, or loads a .mat workspace saved after every time data is read in the previous method. Pressing the 'load old runs' will open a dialogue where one can choose the desired .mat file if there are any. Choosing 'SPEDEgetDATA' will run the m-file of the same name and start collecting and preprocessing of the data. This might take considerable time so care should be taken when choosing the time span. Generally periods of less then one month are well manageable.



Figure 2.7: Get data menu. Also shown is the Zoom menu which has no sub-menus.

Zoom

After pressing this menu item (seen also on figure 2.3.2), one has to, depending on his platform and Matlab version, once click on the window he wants the zooming to be done. After this initial click there are three possibilities, mainly to zoom in, zoom one step back or zoom all the way to the 'no zoom' situation. All of the sub-plots will be zoomed simultaneously. This need forced us to write a separate zoom from the nominal Matlab functionality. One can also use the default Matlab zoom on any separate subplot, but it doesn't quite function for many plots simultaneously and it also doesn't have memory provided by our zoom.

Zooming in happens by first clicking the desired lower limit on any of the subplots with the left mouse button and then doing the same for the desired upper limit. The upper limit can also be chosen first and the same behavior will occur.

To zoom one step back, or to 'undo' the previous zoom, one only needs to click the middle mouse button. All out zoom is acquired by the right click of the mouse.

2.3.3 Reading and Processing Data

Instrument Data

Instrument data has been provided in Planetary Data System (PDS) format [pds06]. Routines to read this data into matrices are used and data in string form (mainly Status fields) are transformed into a numerical form in

order to produce smaller workspace sizes. Status data is by default discarded to save the memory. To save all status data, consult the source code and uncomment lines performing the reading of these data. Reading routines can easily be modified to any type of PDS data or matrix data.

Orbital Data

Orbital data is processed with SPICE IDL library and saved to monthly chunks, see appendix C. As necessary, many of these chunks are then read in order to cover the whole span of the required data reading time (see sec. 2.3.2). As the data is often requested of different periods than a calendar month, the spans of the instrument and orbital data often differ. This is important issue in plotting. The first subplot dictates the span of the x-axis and so if an instrument data is plotted first, the x-span will be tight for the data and neglect loads of orbital data. Correspondingly, if orbital data, say altitude, is plotted first, the plot x-label will span whole months.

Also the EP power data is in this respect read similarly to the orbital data.

2.3.4 Plotting

The simplest way to plot datasets is to select data types from under SPEDE and EPDP menus. To plot another data on the same figure one selects another data type and so on. The data available are colored blue. From under the PLOT menu one can define whether the newest plot will be made on the same subplot (select 'hold on'), on a new subplot ('new subplot', set as a default) or on a totally new figure ('new figure', this feature is not thoroughly tested).

To clear the figure and to set the shortcut (section 2.3.5) back to an empty vector [], one can choose 'clear plot' from the plot menu. To only clear the lowest subplot one can choose 'clear subplot' instead. This removes the last subplot and can be used again and again to erase as many subplots as there is. But the removed subplot is always the last one, there is no capabilities in the program to remove a subplot from the middle of the plot. This could be done but there seems to be no real need for this.

2.3.5 Shortcut

Desired plot might include tens of different datasets and selecting all those from SPEDE-, EPDP-, or Orbit menus every time one wants to plot a certain plot might get frustrating. This is why a shortcut functionality has been introduced into the program. Shortcut allows easy replotting of any desired choice of plots. Shortcut can be reached through the plotting menu but because of its importance it has been here given its own section. When asked through the menu the shortcut of the last plot will be printed on Matlab command line and a dialogue will appear for submitting a new shortcut.

Each data (for example ground voltage, orbit height, ion density etc.) is signed with a two digit identifier. These identifiers can be explored by taking a look at SPEDEkoodisto.m or spede2.m. When plotting a data type by selecting it from under SPEDE or EPDP menus this identifier number is added to a 'shortcut' string. All the identifiers from the same subplot are parsed together and there is only a space signaling the difference between two different subplots.

For an example lets take a closer look at the default shortcut in the program, which is [10 13141257 1618 50]. The first number in this vector, corresponding to the first and uppermost subplot, is ten. From the appendix B we can see that the number ten corresponds for meas_EF, the electric field measurement of the SPEDE probe. The second subplot consists of plot types 13, 14, 12 and 57 being the reference voltages for the first and the second SPEDE probes, ground reference voltage and the V_{crp} or the cathode floating potential. The third subplot is made out of plot types 16 and 18, the ion density from the SPEDE probe and the places of the Langmuir sweeps indicated by the plus signs (by default) or vertical lines (if there is less than 20 places). The last shortcut code, 57, indicates that the last subplot consists solely of the EP power diagram.

2.3.6 Automated plotting routines

The last five options on the 'Plot' menu are automated plotting routines to plot and save certain parts of the big picture. 'Plot power changes' finds and plots

all the EP power change points with some minutes span on both before and after the power step. 'make SPEDE LP jpg plots' on the other hand draws all the SPEDE Langmuir probe sweeps (SPEDElangmuirJPGall.m). These sweeps can also be accessed with 'Analyze SPEDE Langmuir' routine, more of which is discussed in section 2.3.7.

The automated plotting routines usually give the user a dialogue box to have some influence on the naming of the figures. They will always add in the names a hint to the function that created them or on their purpose, i.e. 'dayplot' or 'powerstep'. There will usually also be some running number involved. In the case of powersteps this number is the order number of the power vector point in which the change is observed; in the case of Langmuir Probe sweeps it is the order number of the Langmuir probe sweep on the current workspace. This can be helpful if the user wishes to manually investigate the case further but usually only provides an confirmation that no plots will be saved on top of each other (as there might be two sweeps or event happening at the same second). The time is always included in the name. Some exemplary automatically created picture names are $Powerstep$20031030_1142.eps, $LPsweep$20040121T062616_3.jpg or $dayplotSPEDE$20031115.jpg. If the user is not content with these naming regulations, editing the files running the corresponding automated plotting routines is not too hard but also Perl or other such tools provide fast and efficient means of changing the names.

2.3.7 Plotting and Analyzing LP, RPA and SC Sweeps

All of the EPDP data types and instruments in this chapter are discussed in more detail in the EPDP Flight Data Report [CS05]. In this chapter they are brought up merely in order to discuss the functionality of the developed software. SPEDE measurements are discussed more thoroughly in the following chapters.

Plotting all of the sweep data by choosing it from below SPEDE (Langmuir sweeps) or EPDP (Langmuir Probe, LP, Solar Cell, SC and Retarding Potential Analyzer, RPA sweeps) menus will result, depending on the amount

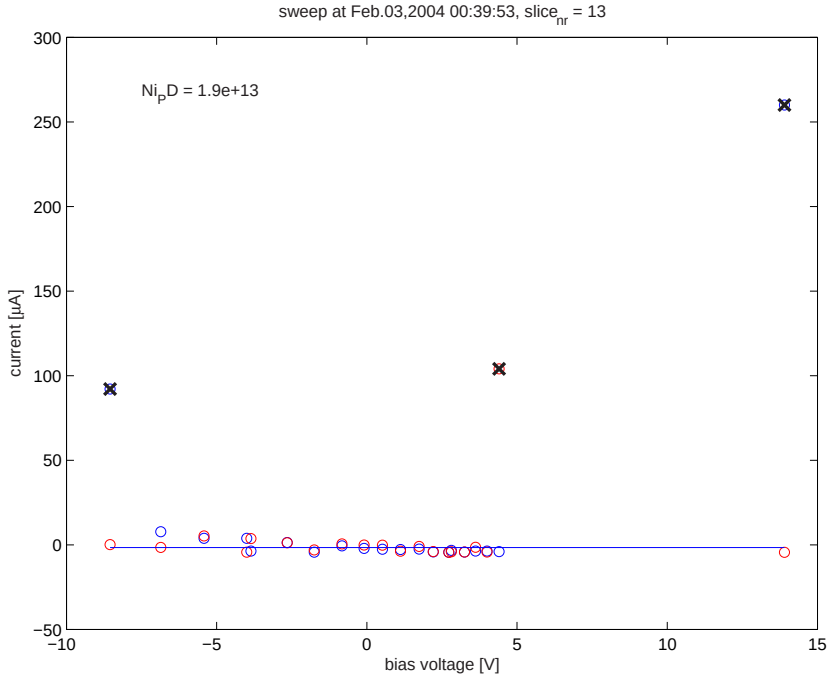


Figure 2.8: Typical SPEDE LP sweep as seen through 'Analyze Langmuir SPEDE' or 'make SPEDE LP jpg plots'. The ion density retrieved from a constant fit (blue line) is also shown in the upper left corner (m^{-3}). Program draws black crosses over data points it has discarded.

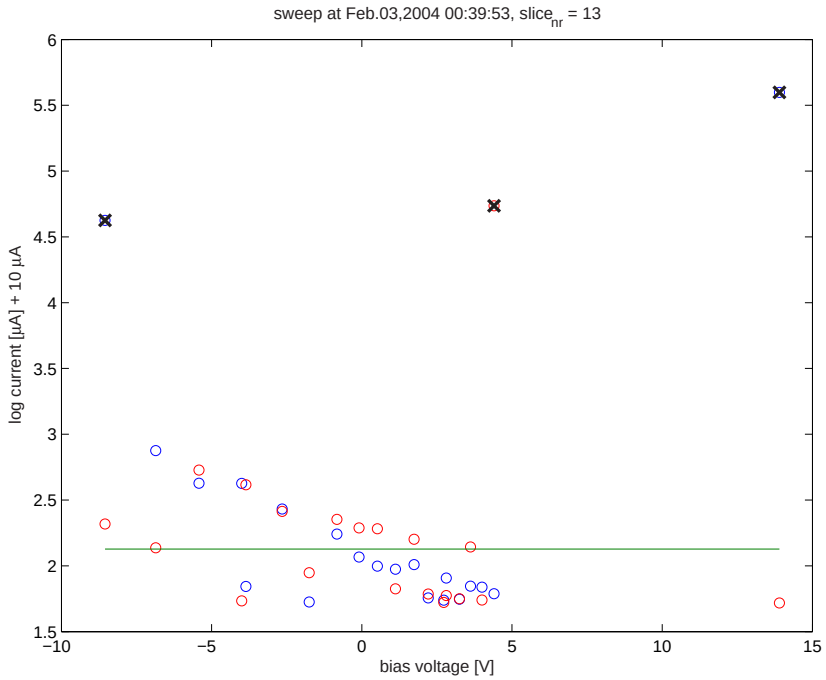


Figure 2.9: The SPEDE LP sweep of figure 2.8 after click of the middle mouse button. This adds 10 μA offset to assure the positiveness of the data, and then changes the y-scale into a logarithmic one.

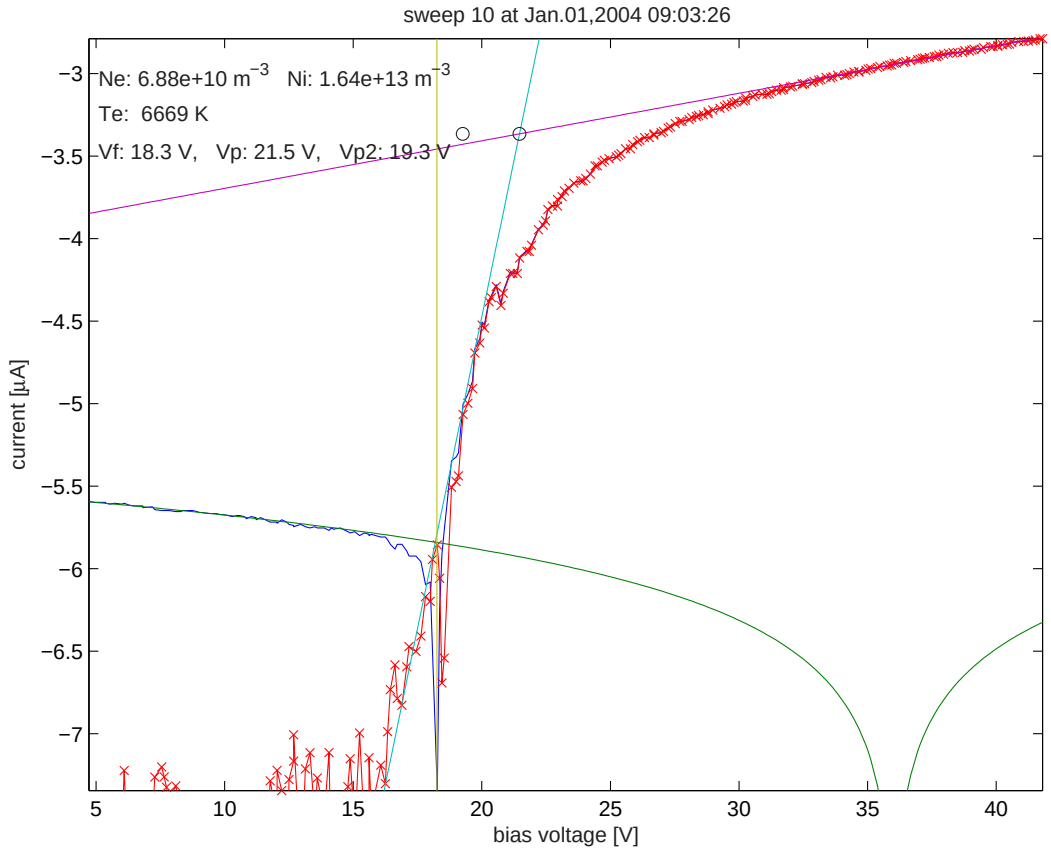


Figure 2.10: EPDP LP sweep analyzed with EPDPlangmuir (or under PLOT menu 'Analyze Langmuir EPDP'). Blue line is the original sweep with clearly bad points removed. Green line is the fitted ion current and the red line with crosses indicate the electron current (original - ion contribution). Turquoise line is the transition region approximation and the purple line is the one for the electron saturation region. Vertical ocher line is drawn at the floating potential V_f and the two black rings represent plasma potentials retrieved in two alternative ways.

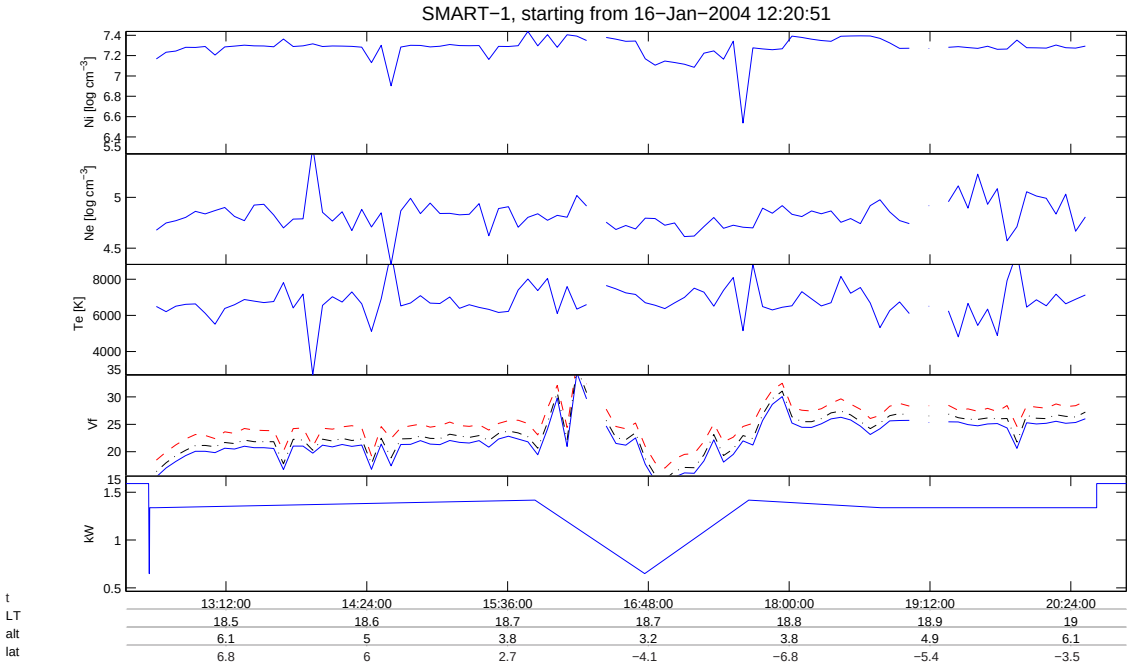


Figure 2.11: Sample of some plasma parameters that can be derived from an EPDP Langmuir sweep, like that in the figure 2.10. The first panel shows the ion density, second one the electron density and the third panel the electron temperature. The fourth panel shows the floating potential (blue), plasma potential acquired from the line fit (red –) and the plasma potential retrieved from the crossing of the transition and saturation regions (black .-). The lowest panel shows the EP power, line being drawn directly between points which might be misleading.

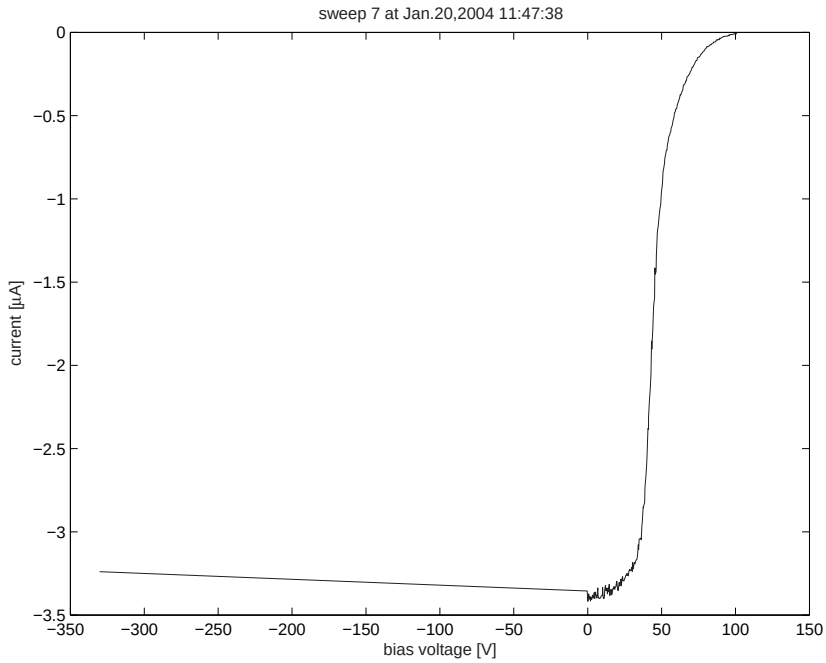


Figure 2.12: EPDP Retarding Potential Analyzer sweep. This figure is the result of left clicking after choosing 'Analyze EPDP RPA'.

of the required markers, in either vertical lines (when less than 20 markers are needed) or crosses being drawn on the times of these sweep measurements. To see the real sweep data one has to choose from under the PLOT menu either one of 'Analyze Langmuir SPEDE', 'Analyze Langmuir EPDP', 'Analyze EPDP SC' or 'Analyze EPDP RPA'. Some of the automated routines also plot and print these sweeps like SPEDElangmuirJPGall.m (see section 2.3.6).

When the 'Analyze Langmuir SPEDE' is called, the script SPEDElangmuir.m is run. This creates another figure and returns the original spede picture with an active pointing cross (produced by Matlab function *ginput*). One has to now click in the original SPEDE picture and the next sweep to the left of the clicking point will be portrayed in the new figure along with a fitted straight ion current line and the retrieved ion density values. SPEDE boom-1 sweeps are acquired by clicking the left button of the mouse whereas the boom-2 sweeps are only plotted when the right button is pressed. By clicking with the middle mouse button the y-scale is changed to logarithmic. So to acquire the a logarithmic sweep of the SPEDE boom-2 one has to first click

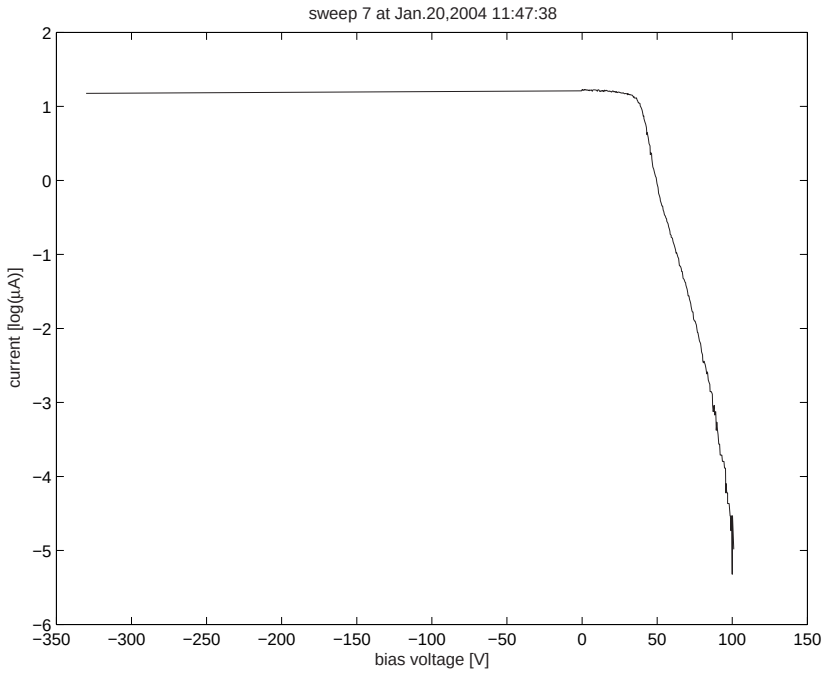


Figure 2.13: EPDP Retarding Potential Analyzer sweep a logarithmic scale. This figure is the result of left clicking after choosing 'Analyze EPDP RPA'. The scale has then been changed into a logarithmic one by a click with the middle mouse button.

with a right button and after that with the middlemost one. The location of the mouse pointer is of no importance when using the middle button. These features have not been tested with Macintosh computers but it is expected that functionality might be somewhat different due to some lacking mouse buttons.

The Langmuir probe sweep in figure 2.8 is a very typical one for SPEDE. In figure 2.8 this same point has been changed into logarithmic scale by pressing the middle mouse button within 'Analyze Langmuir SPEDE' mode. The operation adds a 10μA current offset before taking the logarithm in order to guarantee the positiveness of the logarithm argument. Points residing further than one sigma away from the mean of the points have been discarded and shown in the figure as black crosses, there are typically two or three such points in any SPEDE sweep. This drawing of the sweeps in the 'Analyze Langmuir SPEDE' mode is run in a while loop and thus continues until the user presses

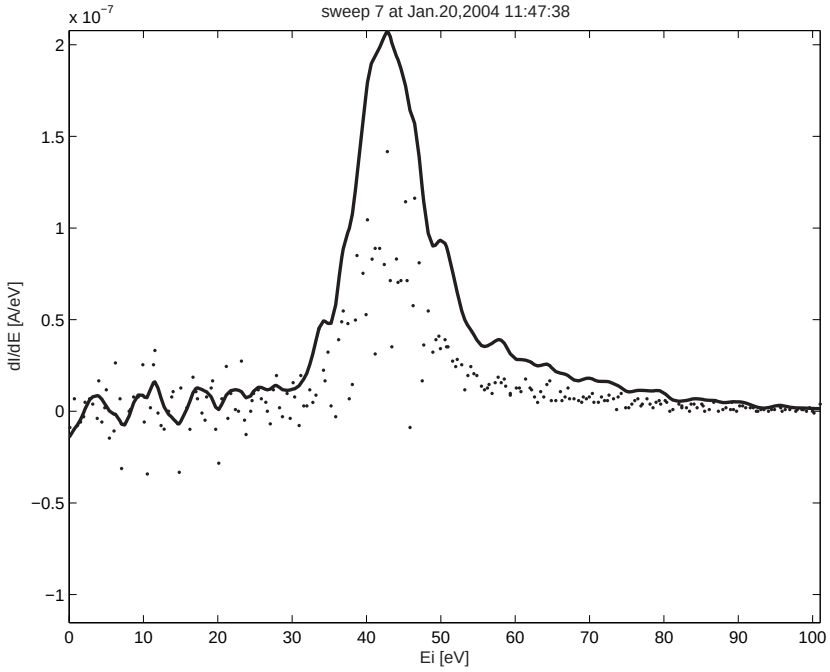


Figure 2.14: EPDP Retarding Potential Analyzer sweep derived to show the energy distribution of the particles. The solid line is a derivative of the smoothed data whilst the dots are gradients of the raw data. This figure is the result of right clicking after choosing 'Analyze EPDP RPA'.

the enter key.

Some of the SPEDE LP sweeps, like the one in figure 2.8, first run up the voltage and then return back within the same sweep. As there is no way of telling from data headers whether a sweep is one-directional or returning, the program always colors first half of the sweep points blue and the rest in red. The average of these ion current measurements is then converted into ion density and also the current EP power, altitude and latitude are shown in the figure. Time can be deduced from the title where also a slice number, slice_{nr}, is shown. This number is only pointing to the order number of this SPEDE Langmuir sweep within those currently loaded to the workspace and thus can not be used to identify any data if the workspace has not also been specified.

Correspondingly the 'Analyze Langmuir EPDP' calls the script EPDPlangmuir.m. This script works in the similar way to the SPEDElangmuir.m in that

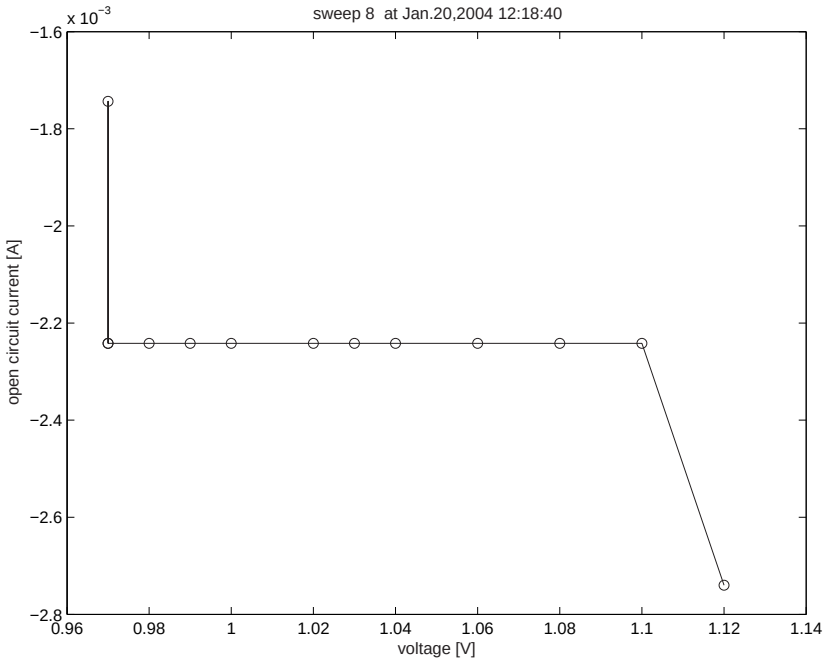


Figure 2.15: EPDP Solar Cell experiment produces characteristics for open, closed and 5 Ohm circuits. Figure shows an open circuit current for a varied voltage and has been directly printed from the 'Analyze EPDP SC' mode of the program.

the left click plots the sweep and the middle changes the y-scale into logarithmic. The difference is in that the right mouse click, which was needed for the other boom in the case of SPEDE, now shows the analysis process of the EPDP LP sweep as shown in the figure 2.10. In this figure the blue line is the original sweep with clearly bad points, usually those with oscillating voltages beyond sweep limits, removed. Green line is the fitted ion current and the red line and crosses indicate the electron current (ion contribution subtracted from the total current). Turquoise line is the transition and purple line the saturation region approximation respectively. The other vertical line is drawn at the floating potential V_f and the two black rings represent plasma potentials retrieved in two alternative ways, first one from locating the peak in the current derivative and the second from the crossing of the transition and electron saturation region fits (turquoise and purple lines). Again a clean exit from the sweep plotting mode can be achieved by pressing the 'return' key.

A sample of some plasma parameters that can be derived from a EPDP Langmuir sweep, like that in the figure 2.10 is shown in the figure 2.11. The first panel shows the ion density, second one the electron density and the third panel the electron temperature. The fourth panel shows the floating potential (blue), plasma potential acquired from the line fit (red –) and the plasma potential retrieved from the crossing of the transition and saturation regions (black .-). For a more thorough explanation of this analysis method, please consult the Demeter software report [Mer06].

The Retarding Potential Analyzer (RPA) also produces data in sweeps and this data can also be separately studied sweep by sweep with the EPDPlangmuirRPA.m routine which is called when the 'Analyze EPDP RPA' option under the PLOT menu is chosen. Any RPA sweep can be looked at by left clicking the original image after choosing 'Analyze EPDP RPA' from the PLOT menu. This runs the EPDPlangmuirRPA.m script that works in similar fashion to the SPEDE and EPDP Langmuir probe analysis scripts previously discussed. A typical successful RPA sweep is shown in figure 2.12. The same sweep in logarithmic scale (after a middle mouse click) is displayed in figure 2.13.

Again, as was the case for EPDP LP, the right mouse function was left free for some analysis tool so a derivation of data was set to be triggered from there. In figure 2.13 the result of right clicking when in 'Analyze EPDP RPA' mode is shown. Dots show the gradient of the raw RPA sweep. The solid line is showing the derivative of the smoothed RPA sweep (this requires Matlab spline toolbox). This allows the energy distribution and population analysis of the particles hitting RPA [MS05]. An automated retrieval of the mode of this distribution could be straightforwardly added to the program if a need arises.

The data from the EPDP Solar Cell experiment (SC) is also delivered in sweep form. Although these sweeps do not look very informal as such, a tool was developed for them in the same style as for all the other sweep data. To run this tool one has to either choose 'Analyze EPDP SC' under the PLOT menu or type $EPDPlangmuirSC$ on Matlab command line. From left click the open circuit sweep is plotted whereas from the middle mouse click the closed circuit characteristics are revealed. Current through a 5 Ohm resistance for

different voltages is shown when the right mouse button is clicked. A clean exit from the analysis state again requires a press of 'return' key. One quite nice SC sweep is shown as an example in figure 2.15.

2.4 Example Run

In this chapter a simple example is gone through in data reading and plotting. Example run of the program would start with the command 'spede2' which launches the user interface. Some crucial variables, like 'shortcut' and time pointers are saved within some elements of this user interface so first running 'spede2' is necessary for running most of the scripts included in the program.

2.4.1 Getting Data

The data is acquired by selecting the submenu 'SPEDEgetDATA' under the 'Get data' menu. This produces the following Matlab command line output:

```
_____ Reading data for 20.1, 2004, folder MO
* HK file found for date 040120
* EF X1 file found for date 040120
- no EF X2 file found for date 040120
* PD X1 file found for date 040120
- no PD X2 file found for date 040120
* 16 EPDP LP files found on date 20040120
* 15 EPDP QCM files found on date 20040120
* 15 EPDP RPA files found on date 20040120
* 15 EPDP SC files found on date 20040120
converting time formats
converting orbital time strings to vector..
converting Status strings to numbers (smaller is better)..
Reading Kp index
Reading EP power data
Reading Ucrp data
```

```
**********  EPDP_LP ivan loop begins, takes a few minutes..
more than 1 Vf. Bad data at sweep 1? abandoning this sweep.
..done! Our data had 13 good and 3 unsuccesful iv-curves.
Reading (and processing) data took 0.62681 minutes.
**********  writing on a file, takes a moment...
workspace saved in file Soutput/Spede_M0_040120_040120.
Took 0.025845 minutes.
```

From this output it can be deduced that the program just fetched the available data for January 20th, 2004. It found a housekeeping datafile, electric field experiment file for the X1 probe and a plasma diagnostics file. For this day it also found 16 EPDP Langmuir probe files (which might contain more sweeps), 15 QCM, 15 RPA and 15 solar cell sweep files. After reading in all these data some processing of mainly the time formats is done so that they all agree with the Matlab UTC. Strings are converted to numerical form to save the disk space and memory. Kp index, Electric Propulsion power and U_{crp} data are read separately from ASCII files provided by ESTEC team members.

iv-analysis is then done for all the EPDP Langmuir sweeps. The algorithm there is inherited but enhanced code used to analyze DEMETER satellite Langmuir sweeps. For this EPDP algorithm a use of the Matlab spline toolbox has been taken which has provided better results and shorter code. After all of the data is ready to be plotted, the workspace is saved for future use.

2.4.2 Plotting Data

After the data is read into the program one can start selecting data items from under SPEDE and EPDP menus. A faster way to a plot though is to choose the 'shortcut' option from the 'Plot' menu. It will print the current shortcut on the command line:

```
Current shortcut code is:

shortcut =   0
```

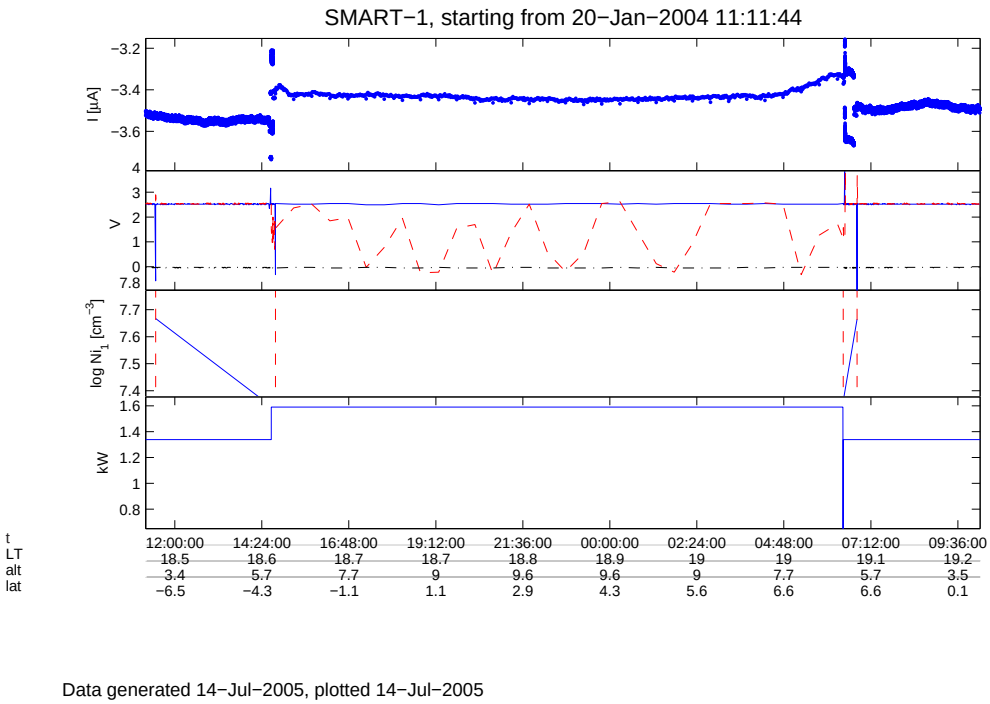


Figure 2.16: Example plot of the default run (Chap. 2.4). X-axises show mission time (t), local time (LT), altitude from the surface of Earth (alt) and latitude (lat). All are linearly interpolated from 'EF' datasets.

and open a dialogue box with a suggested default shortcut: [10 13141257 1618 50], see section 2.3.5. By pressing 'OK' you accept this to be the new shortcut, you can also edit the selection if you wish. After this, you need to just press 'redraw' under 'Plot' menu and the image is printed to you. This image you then can save by choosing 'fig –> ps, jpg' under the 'Plot' menu and inputing your desired filename on the appearing dialog box. The result of the ps printing is shown in figure 2.16. TIP: You might try pressing 'redraw' more than one time as the program might adjust the axis to look better after another redraw.

2.5 Trouble Shooting

In this section some common causes of difficulties in using the program are pointed out.

2.5.1 Pressing 'redraw' and nothing happens

For big data amounts redrawing the figure might take longer than expected, up to a minute in extreme cases. There is also a possibility that the workspace is empty and that there thus is nothing to plot, so be sure to load some data before trying to plot it!

2.5.2 Axes in the figure are messy and unclear

Plotting routines of this program heavily utilize Matlab's subplot routines and a helper function, *subplotspace.m*, which was downloaded from the Matlab's File Exchange and is used to parse out the spaces between consecutive subplots. In the 'Plot' menu there is a switch, 'remove y-spans', to turn this parsing on or off. Some times Matlab gets confused and produces unclear or messy plots. Best cure is to take note of the shortcut (sec. 2.3.5), use the 'clear plot' from the PLOT menu and then reinsert the shortcut (which is erased by 'clear plot'). 'Redraw' should now, on an empty canvas, be able to make a better job.

Sometimes better alignment of the subplots is achieved by resizing the figure or by using 'redraw' two times in a row.

2.5.3 Loaded new workspace and figures are empty

When loading a new workspace .mat file after analyzing some other data on the program, one must use 'clear plot' before plotting anything as the time span of the previous workspace is in the memory. Thus the plot routine tries to plot the new data on the old axis and usually cannot find anything so the plots produced are empty. 'Clear plot' also clears those old axis limits from the memory and a more accurately aimed plotting can proceed. But a note should be taken that clearing figure with Matlab's own 'clf' command is not working with this program as the 'clf' also clears the menu items and all the crucial program variables associated with those GUI items.

Chapter 3

Early Analysis

SPEDE Langmuir probe was on doing the electric field measurements during most of the power level steps. Here a look is taken on 83 of these incidents found on October 2003, 49 of November, 19 of December and 50 of January 2004. Thus we here summarize 201 of monitored early mission Electric Propulsion (EP) power changes.

On most of the plots of this chapter four subplots are shown. If not otherwise noted, the uppermost one is the SPEDE Electron Flux measurement of the working probe, the second one shows the reference voltages (often oscillating red one indicating the reference voltage of the malfunctioning probe-2). The reference voltage of the malfunctioning probe is also plotted because its fluctuations seem to correlate with those of the functioning probe-1 [Mal04]. In the third subplot the places of SPEDE Langmuir sweeps are shown with black '+' marks and the ion density deduced from these sweeps is plotted with blue. The lowest subplot presents the Electric Propulsion power level, line being drawn directly from one data point to another although it seems likely that the power changes in reality are rather steps than continuous slopes. These plots have been produced with the automated plotting routine 'Plot power changes' (plotPowerChanges.m).

In this chapter data from September 2003 till February 2004 is summarized in monthly sections.

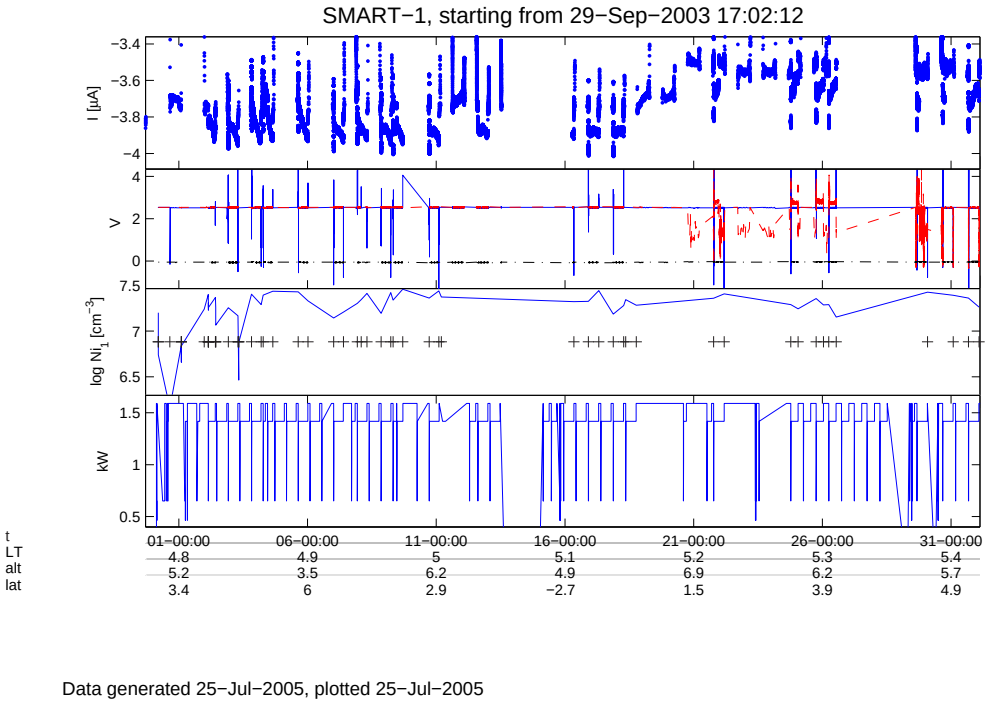


Figure 3.1: SPEDE plot of September and October 2003

3.1 September and October 2003

The first SPEDE data we have is from the 29th of September 2003 till the end of October 2003. During this time the SMART-1 orbit had almost 70 loops around Earth. The orbit apogee stayed between six and seven Earth radiis (Re). We have here merged those two September days into the October to retain meaningfulness of the first monthly summary which is shown in figure 3.1 where two distinct electron flux level changes are seen. In these months the SPEDE was monitoring during three different kinds of power changes; we only report on those which SPEDE was on to observe. An example of the first type is shown in figure 3.2. There were twenty of these dips occurring when the SPEDE was on, only one of those twenty showed a clean response while the others were at times oscillating between two electron flux values. This problem is related to a certain mode configuration at the early days of the mission, and corrected for the most recent data sets that have recently come available. Also the reference voltages had typically three spikes (though in figure 3.2 reference voltages are not oscillating), usually coinciding with the beginning of these EF

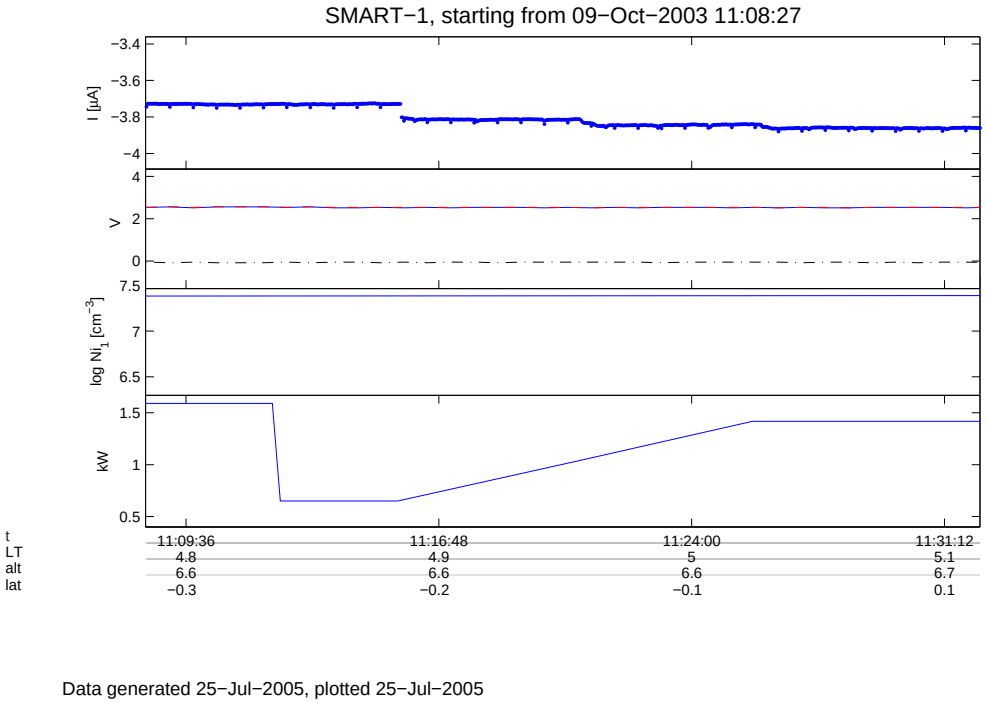


Figure 3.2: A typical power dip with a well behaved EF reaction in October 2003. There seems to be time correlation problem with the measurements and the EP power data.

oscillating periods. In October 20th the SPEDE probe-2 reference potential started to oscillate. Unfortunately this behaviour prevailed which is the reason why we almost exclusively concentrate on the probe-1 data.

The second type of power change, simple step seen in figure 3.3 is usually following a first type of power change. This step was also observed by SPEDE twenty times, only three of these, from 22th, 30th and 31st of October, were without any visible change in Electron Flux experiment. One of these three is shown in figure 3.4. The reason why the effect of the power change has failed to cause any effect on EF data in these three sweeps can not be explained by orbit height, local time or reference voltage oscillations as cases with similar values in these variables have been observed with a clearly visible EF response. The SPEDE sampling rate is changed to a more frequent one before the power step. This can be seen as a line type change in the figure 3.4.

Third type was twice occurring mild raise in power level as can be seen

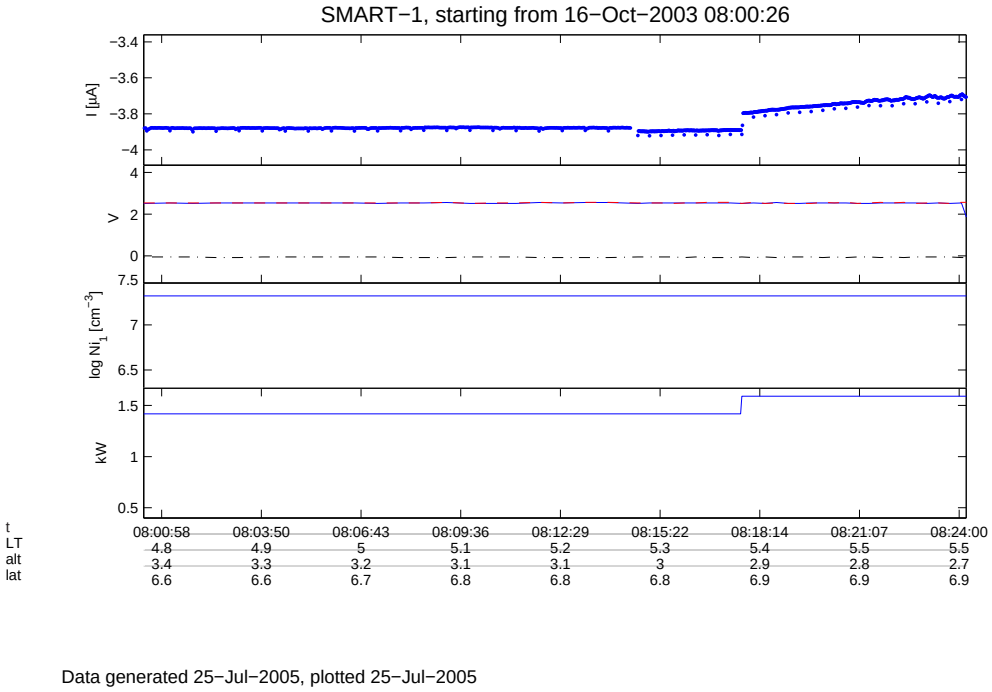


Figure 3.3: A typical powerstep with corresponding EF level step on October 2003. Note the higher sampling rate starting before the power step. Together with the sampling frequency also the bias voltage is adjusted. This results in a visible jump on the EF data, as is demonstrated in the figure.

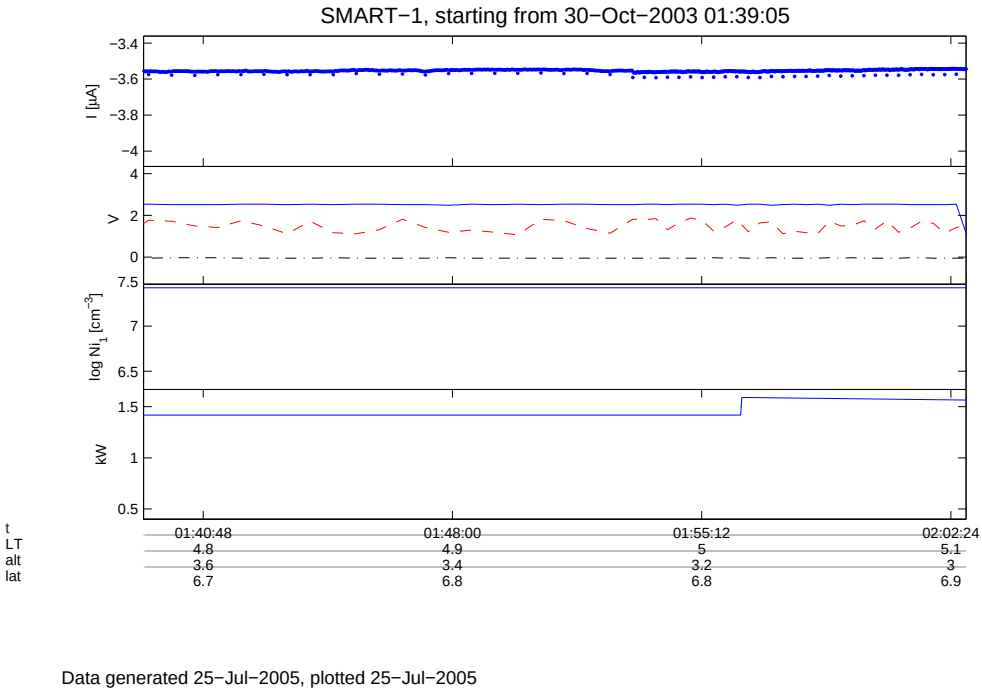


Figure 3.4: A case of no EF reaction for a small power step on October 2003. As in figure 3.3, we see again the jump caused by the change of sampling frequency.

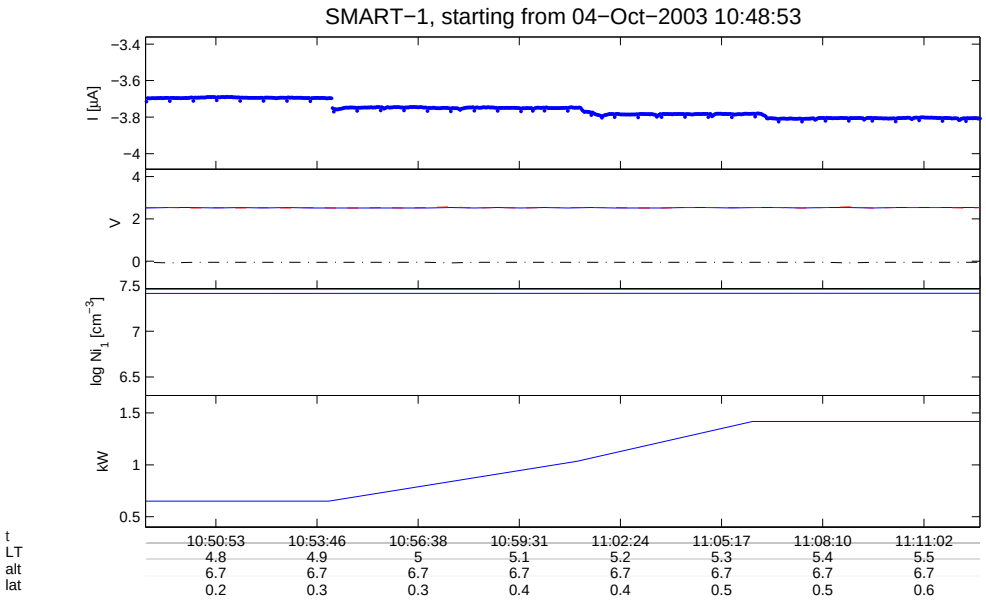


Figure 3.5: The third type of power step observed during October 2003. The power data is in figure represented by only three data points, one in the middle and two on each end of the power slope. The real power behaviour is more likely to be stepwise rather than continuous slope as is shown in the figure. Timely step responses of the EF-data also support this assumption.

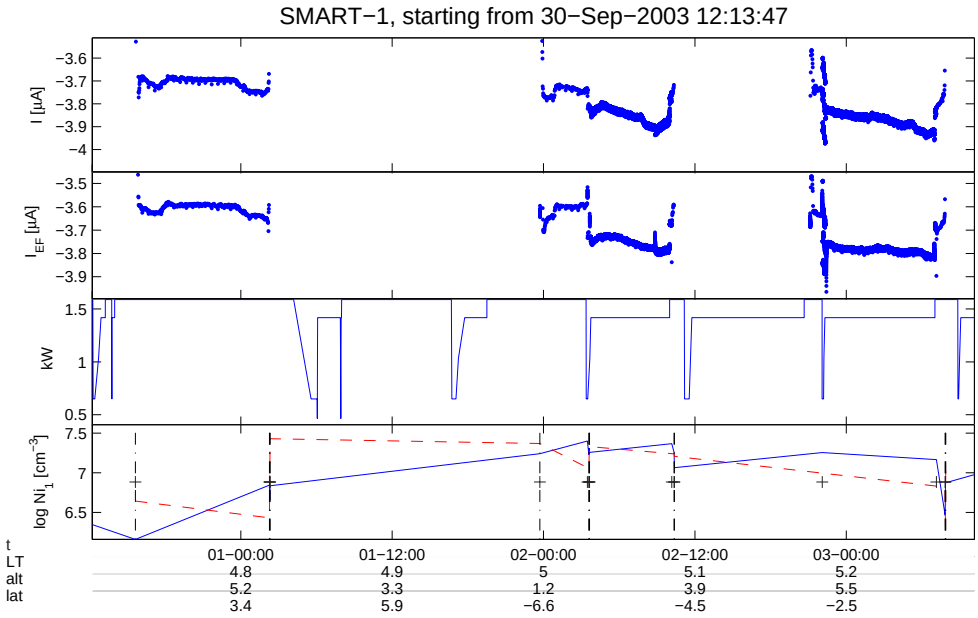


Figure 3.6: The only period of simultaneous good Langmuir probe sweeps occurred during the September 2003. After this probe-2 was not used for Langmuir sweeps before it started to malfunction in the end of October. The EF measurements of probe-1 (highest subplot) and probe-2 (second subplot panel) agree very well with each other while the same cannot be said on the ion densities retrieved from the probes (lowest panel, blue is probe-1 and red probe-2 ion density. vertical lines mark times at which probe-2 was doing Langmuir sweeps, corresponding markings for probe-1 are black '+' signs). In the third panel the EP power level is shown.

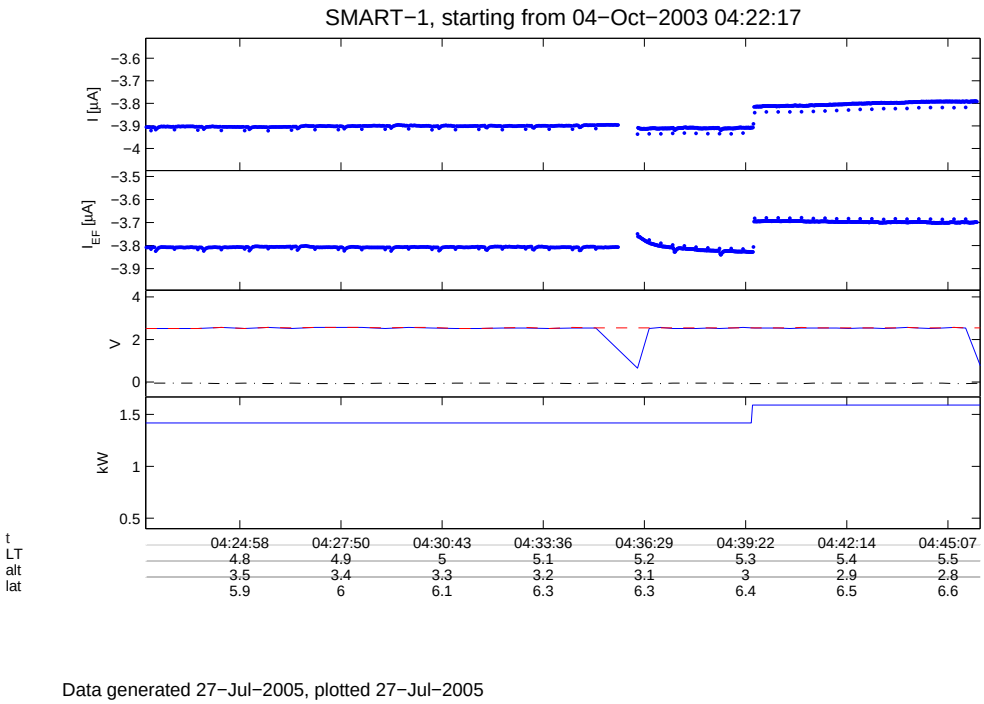


Figure 3.7: Comparison of probe-1 and 2.

in figure 3.5. The response to this was first in the start of the power step a sudden EF step to higher currents (note the negative sign in EF y-axis), after which there are two additional small and well behaved, but still distinct power level changes during this power change event. Reference voltages were stable, which indicates that the EF values are also reliable.

The only period of simultaneous good two probe Langmuir probe sweeps occurred during the September 2003 and is shown in figure 3.6. After this probe-2 was not used (or the data is lacking) for Langmuir sweeps before it started to malfunction. The EF measurements of probe-1 (highest subplot) and probe-2 (second subplot panel) agree very well with each other while the same cannot be said on the ion densities retrieved from the probes (lowest panel, blue is probe-1 and red probe-2 ion density. Vertical lines mark times at which probe-2 was doing Langmuir sweeps, corresponding markings for probe-1 are black '+' signs). It is however questionable whether ion densities should even be expected to be same on different sides of the spacecraft. In the third panel the EP power level is shown.

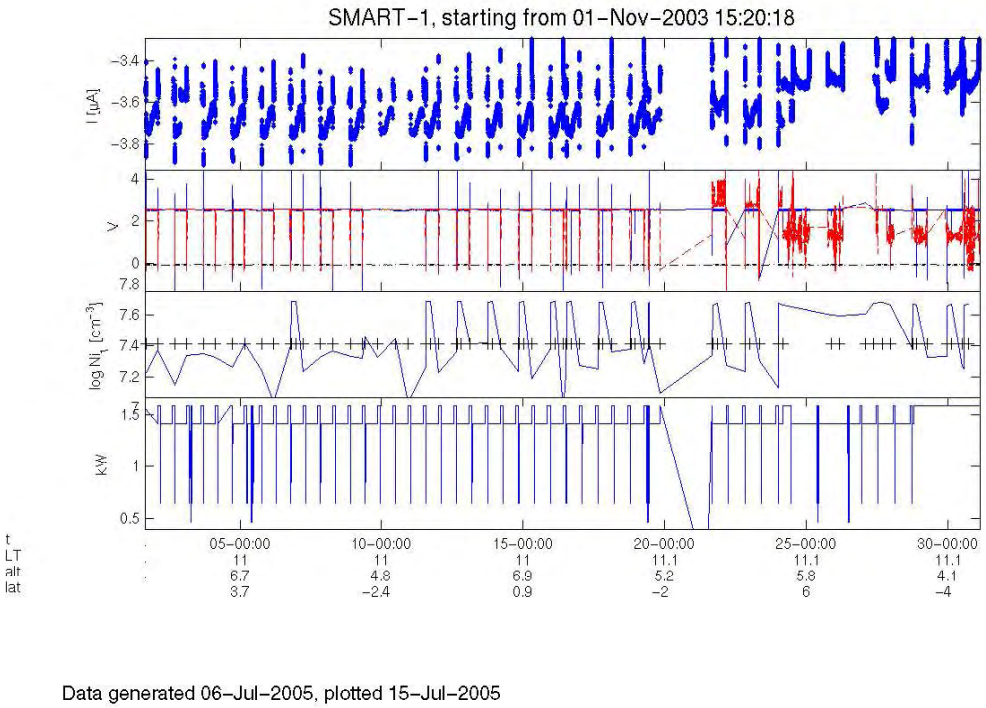


Figure 3.8: SPEDE plot of November 2003

Figure 3.7 presents additional comparison between the responses of the two probes. While the probe-2 was properly working, its reference voltage almost never oscillated which can not be said of probe-1 occasionally exhibiting spikes in its reference voltage. Thus it is interesting to note that the probe-2 responds with more arched and spanning EF current in case of power steps. It is also the probe that seems to react in case of probe-1 reference voltage spike. This also gives strong reason to assume that also probe-2 reference voltage oscillations have an effect on probe-1 measurements which is why both reference voltages are displayed in most of the plots here.

3.2 November 2003

The summary plot of November 2003 is shown in figure 3.8. SPEDE was on during 25 straight power steps. Clean power steps, like the one in figure 3.9, started having EF responses that are considerably stronger than on October steps (fig. 3.3) although the altitude differs only by some tenths of an Earth

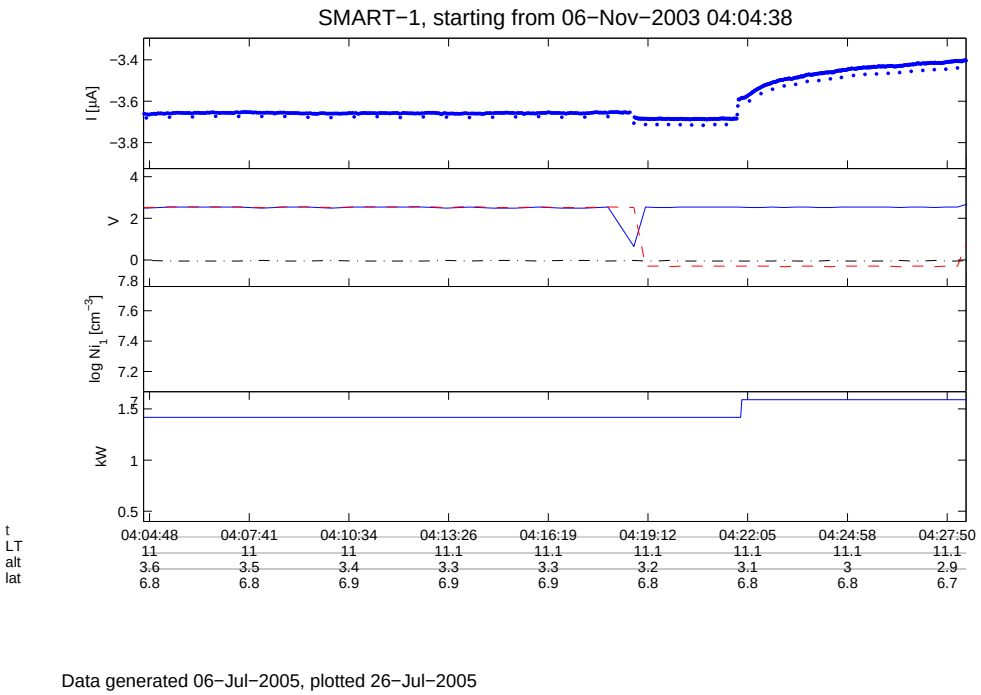


Figure 3.9: A straight power step with a nice EF response in November 2003. The step response is considerably larger than on October steps (fig. 3.3)

radii. The explanation for such differences probably lies in differing local times and different spacecraft orientation or even in a migrated off-set voltage.

A new type of power change was also observed in November. There were two of these sharp power cuts, one of which is shown in figure 3.10. It is curious to note that the EF response follows only about three minutes after the power dip which is a strong indication of time-tagging problems. The other one of these incidents is shown in figure 3.11. In this case there seems to be a delayed as well as an immediate response to the power change. Existence of an immediate effect seems to affirm that the delayed response is real and not caused by any time-tag mismatch in the data. Reference voltages of both booms have some oscillations after Langmuir Probe sweep (black '+') and three minutes after powerstep the EF measurement of uncorrected data starts to oscillate between two values (this anomaly is known to be caused by mode changes and is corrected in final data-products).

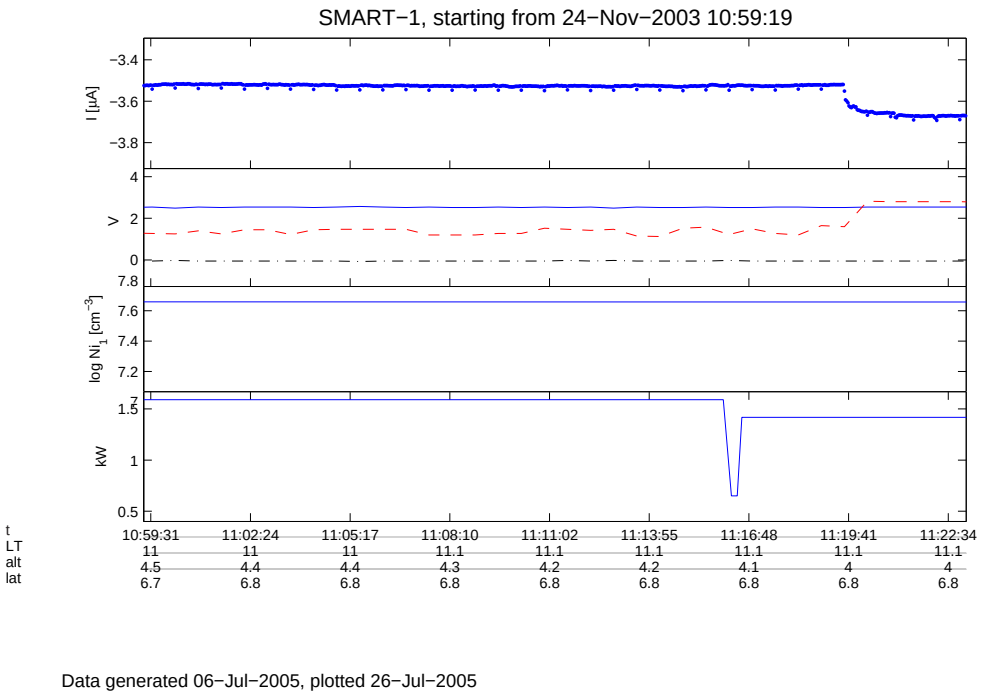


Figure 3.10: Sharp power dip in November 2003. The EF response has been delayed by about three minutes.

3.3 December 2003

In the second half of December 2003 there was a long period of constant EP power levels as can be seen in monthly summary figure 3.12. Because of this only 8 normal powersteps and 11 abrupt power dips were observed with SPEDE. Only one of them, occurring on the 18th day, was clean like the response in figure 3.10, the rest were more or less following the more fluctuating example seen in figure 3.11 and the straight power step responses were similar to November cases.

In figure 3.13 a zoom of figure 3.12 is displayed on a time when EP had a constant level. From this picture we thus can observe a seemingly correlation of altitude and Electron Flux measurement. A maximum of EF occurs always in the minimum altitude, both because of the orbital effects and the fact that EP is usually used at perigee and also because the spacecraft orientation changes with respect to the Sun in synchronisation with altitude changes. Changes in EF signal correlate also with changes in the spacecraft potential derived from

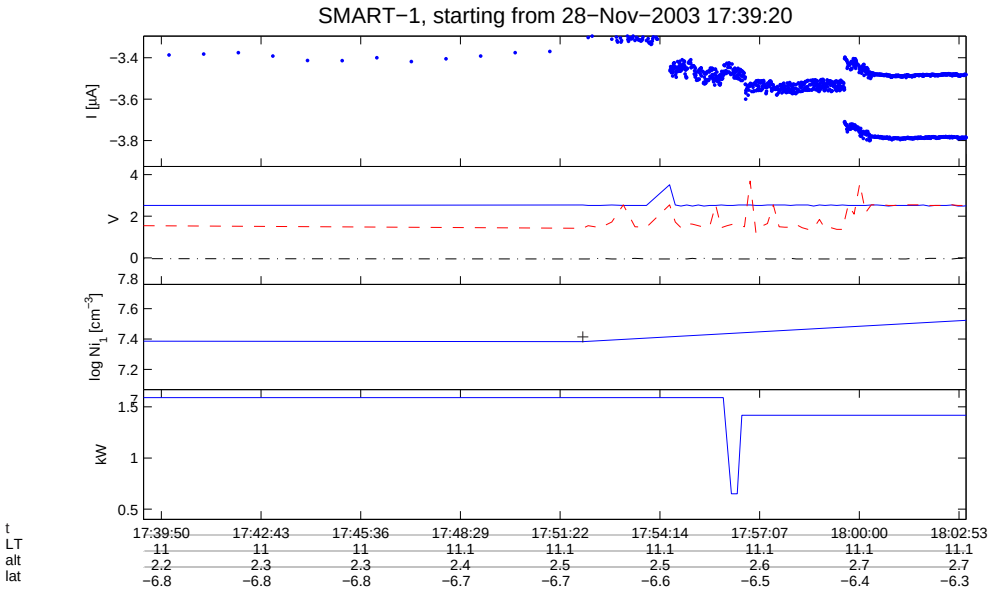


Figure 3.11: Sharp power dip in November 2003. There is a delayed as well as an immediate response in this case. Reference voltages of both booms have some oscillations after Langmuir Probe sweep (black '+') and three minutes after powerstep the EF measurement starts to oscillate between two values (mode change, uncorrected data used). Note also the EF-voltage drop associated with reference voltage spikes almost three minutes before the EP power event.

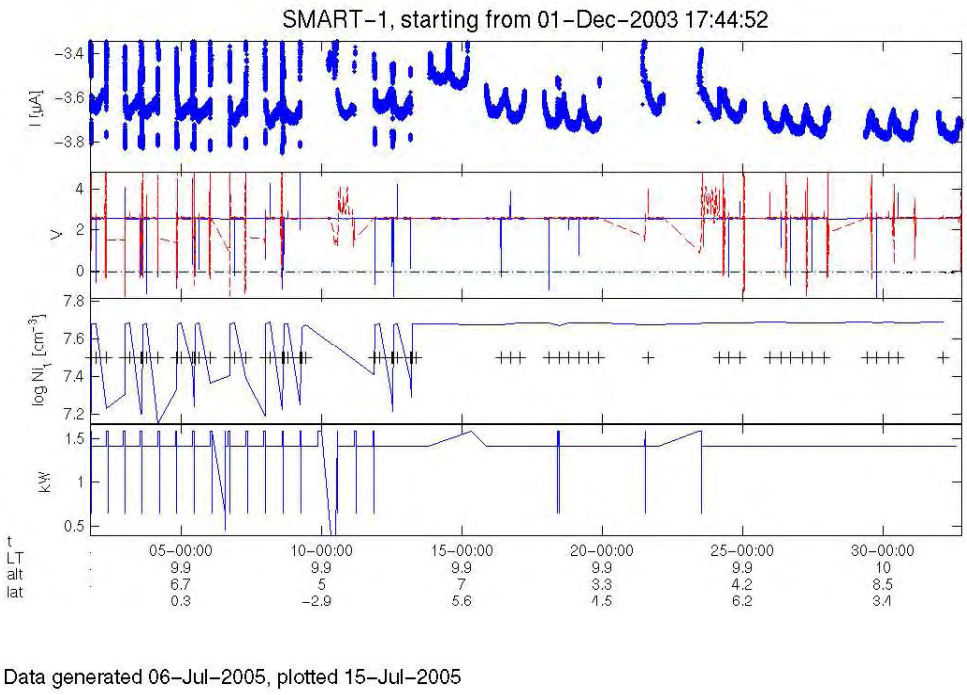


Figure 3.12: SPEDE plot of December 2003

EPDP Langmuir Probe measurements. The actual physical mechanism is not known, but configuration of the spacecraft with respect to the solar irradiation is expected to be a strong factor. Two power pulses close to the noon of the 18th day are also immediately visible in the EF data.

A whole power step is shown in figure 3.14. It is composed first of a simple power step and then of a power dip, both of which have been generally treated as independent power change events (see previous sections of monthly reviews for October and November). SPEDE probe is making Langmuir sweeps very seldomly but even with those few measurements a clear increment of ion density after power raise of EP can be detected. The EP is usually used close to the perigee of the orbit (lowest panel in figure 3.14).

Another zoom of figure 3.12 is displayed in figure 3.15 showing a power step on the left of the figure. Curiously enough half a day later on the right side of the figure a similar EF and Langmuir retrieved ion density give a similar response to a nonexistent powerstep. Perhaps our EP power data is not complete or the response of the SPEDE instruments is solely to the orbital

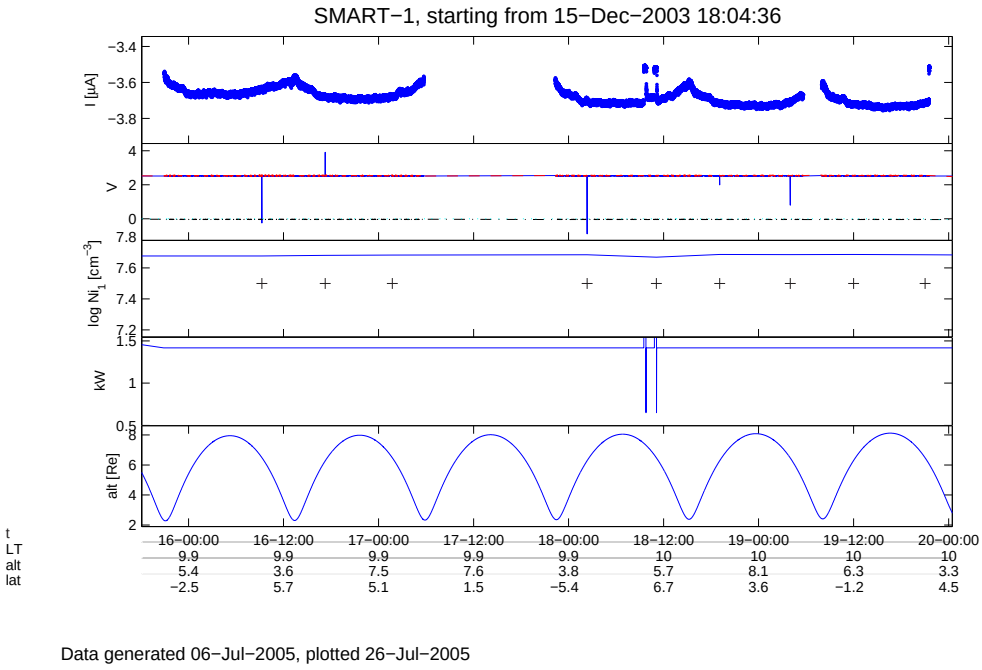


Figure 3.13: A zoom of figure 3.12 with an added altitude panel. This zoom is from a time when EP had a constant level and thus we can observe the correlation of altitude and Electron Flux measurement. A maximum of EF occurs always in the minimum altitude. Two power pulses close to the noon of the 18th day are also immediately visible in the EF data.

and thus ionosphere region changes.

3.4 January 2004

January 2004 starts with a seven day pause of EP firing as can be seen in figure 3.16. For some reason after this pause when the periodical firing of the EP resumes, it takes more than a week for this to be observed from the Langmuir sweep retrieved ion densities, a close-up of this period is shown in figure 3.17. This prompts for a re-check of our data and program time stamping which is TBD. A similar time span and power changes are shown in figure 3.18. This time there is an expected response in the ion density and also less fluctuations in the probe-1 reference current. The EF also has

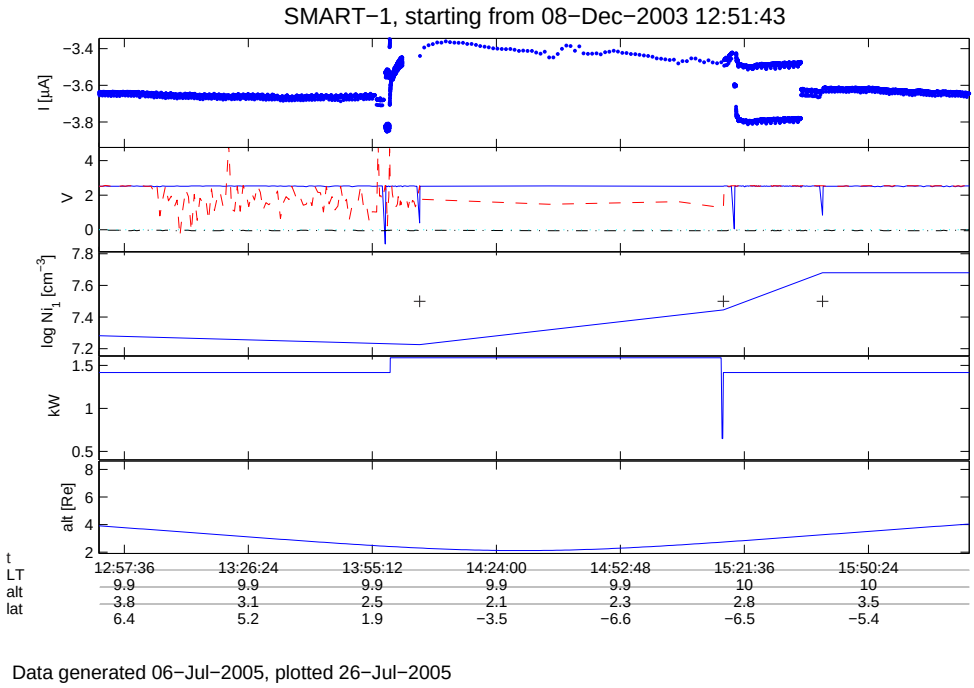


Figure 3.14: Another zoom of figure 3.12 showing a whole power step which is composed first of a simple power step and then of a power dip, both of which have been in this summary generally treated as independent power change events.

a more structured and better matching response. This might be one of the cases where the reference voltage fluctuations or probe-2 are disturbing probe-1 measurements [Mal04]. During the 32 SMART-1 January orbits the apogee rises from less than 9 Re up to more than 10 Re.

In January there were 22 simple power steps and 23 power dips like that in November figure 3.11. Before the 15th day they all had clean responses without fluctuating values. The second half of the month, and thus also most of the power steps, were mostly very noisy and oscillating. Interestingly the EF response to a simple power step is most often almost immediate while it takes usually more than three minutes for the EF to react for a power dip.

On the seventh day there was an interesting power excavation and curiously this triggered no response whatsoever on EF, see figure 3.19. The altitude of almost nine Earth radiis could be the cause of this lack of behaviour or maybe this is one more indication of our EP-Power timestamp mismatches.

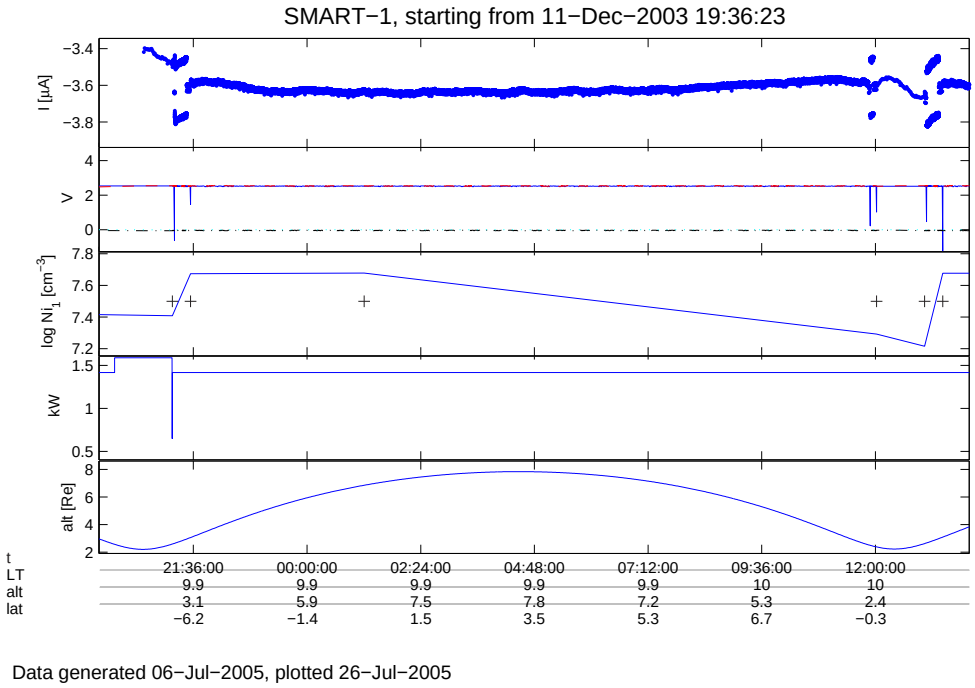


Figure 3.15: Another zoom of figure 3.12 showing a power step on the left of the figure. Curiously enough half a day later on the right side of the figure a similar EF and Langmuir retrieved ion density give a similar response to a non-existing powerstep which indicates that our EP-Power datasets are incomplete.

Sometimes it seems that the probe-2 fluctuations are triggered by the power changes as in figure 3.20. The level of the EF current after the step also stays more stable than for lower altitude (3.3 Re as opposed to 6.3 Re) steps of October (Fig. 3.3) or November where the rising of the EF level after the step most likely relates to the lowering of the orbit.

On the seventh of January there were many interesting events one of them being a double dip in power (figure 3.21. Surprising in this event is that the EF response comes three minutes after the second dip like there would not have been a first dip at all. Unfortunately there were no SPEDE Langmuir sweeps during this period (no '+' signs on the third panel).

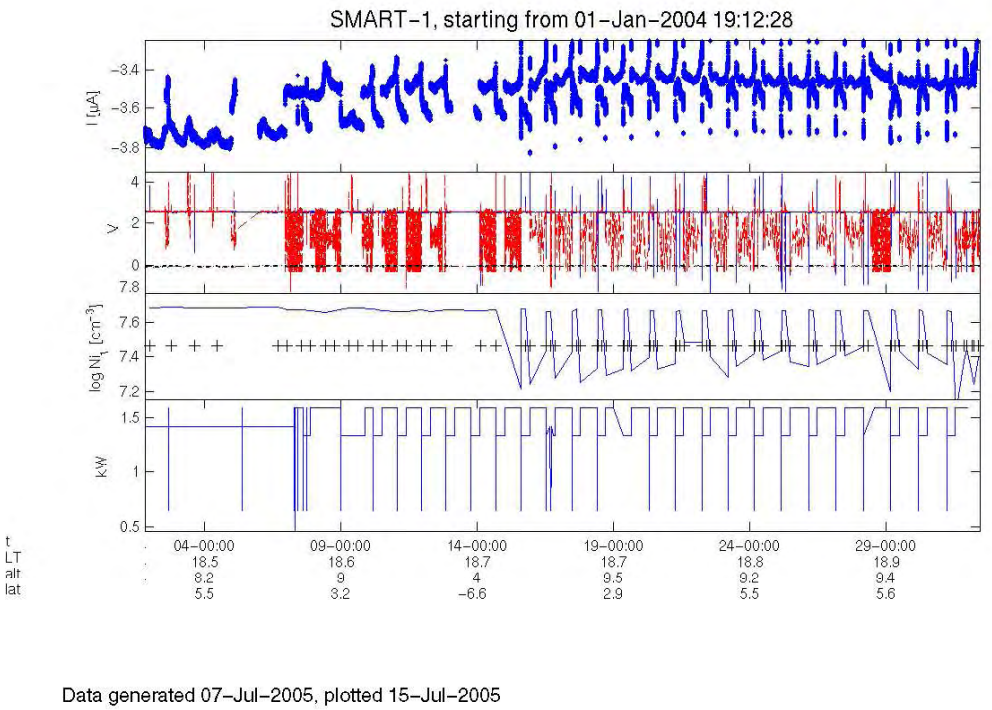


Figure 3.16: January 2004 starts with a seven day pause of EP firing.

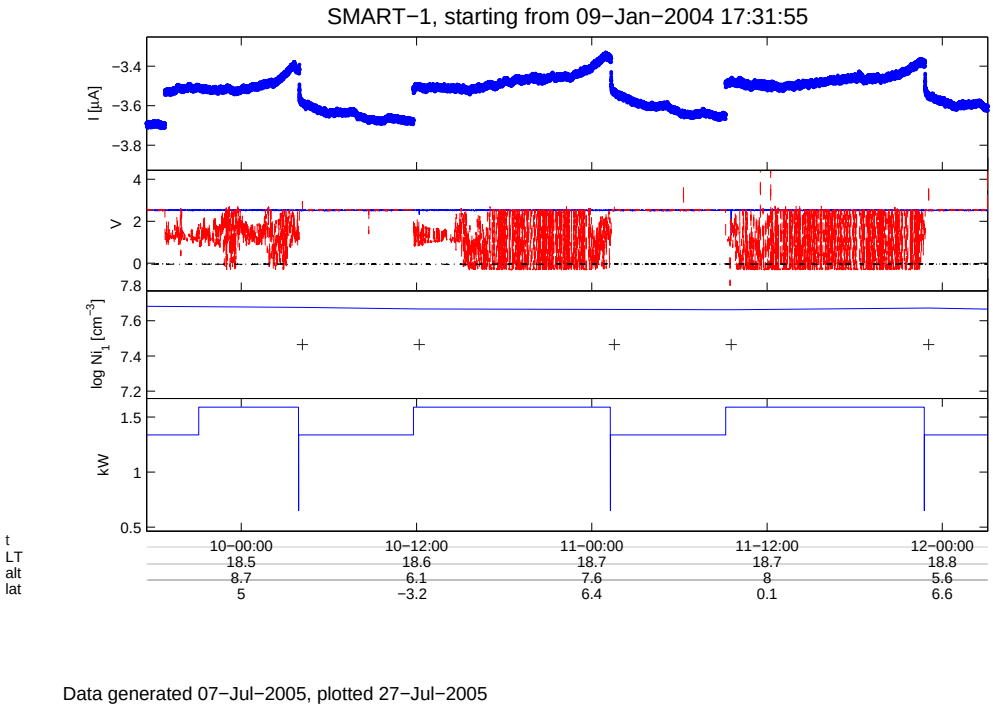


Figure 3.17: When the EP usage resumes after a long break, it fails to raise any effect on SPEDE Langmuir sweep retrieved ion density.

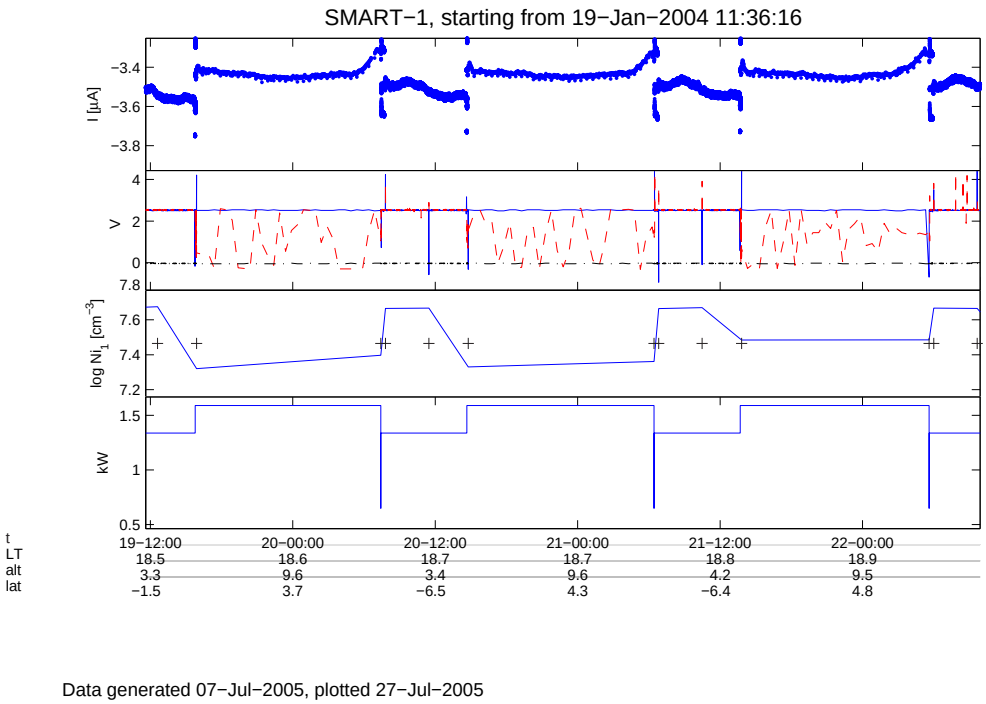


Figure 3.18: Expected response for EP power changes towards the end of January 2004.

3.5 February 2004

For the most of February 2004 our Electron Propulsion power data, the lowest panel in figure 3.22 suggests that there were no power level jumps whatsoever. But this is highly susceptible as the instruments continue delivering data as if the EP was on like was the case in December figure 3.15. It is thus possible that our unofficially acquired EP power data is just lacking some information there. One closer look on this 'no power changes' region is taken in figure 3.23. There we observe probe-2 reference voltage oscillations and probe-1 EF response which are not in phase with orbital changes but match well each other in timing. Nevertheless the SPEDE Langmuir ion current seems to have some correlation with the altitude changes as would be expected.

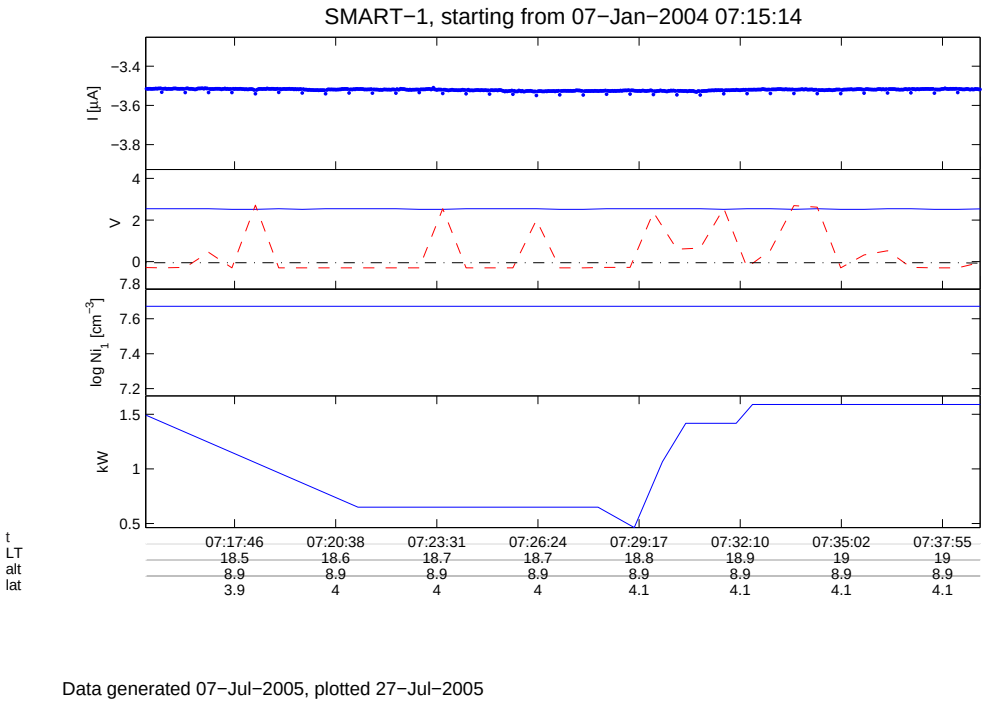


Figure 3.19: HF failed to indicate this huge EP power cut down on 7th of January 2004.

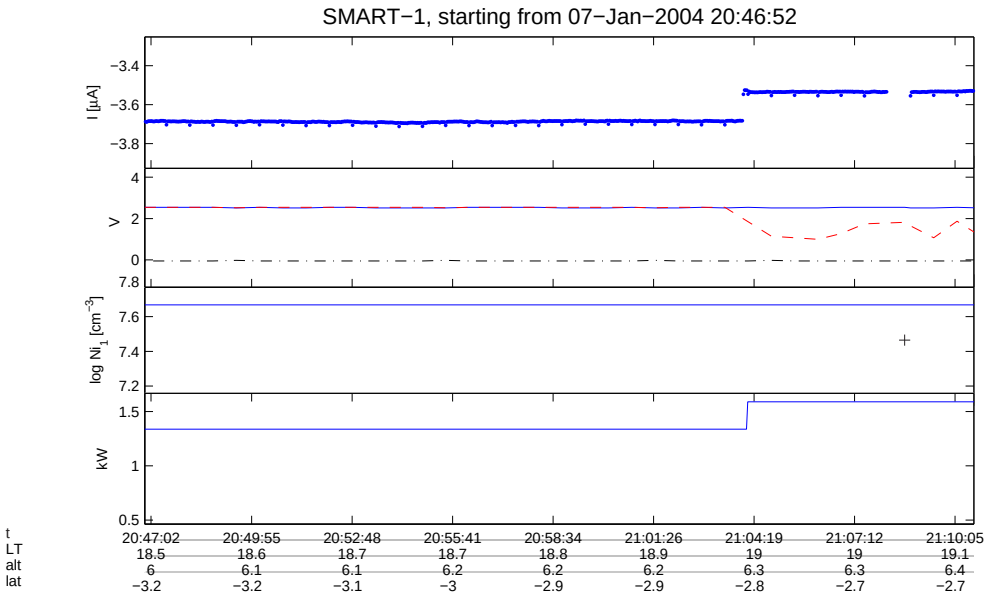


Figure 3.20: January 2004 response for a simple power step. The probe-2 voltage only starts oscillating after the powerstep.

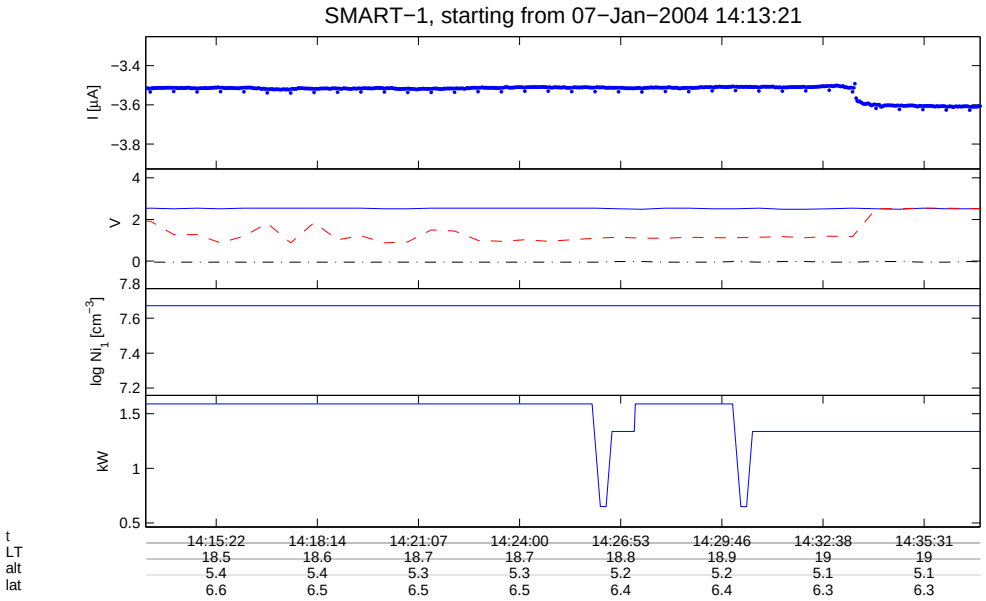


Figure 3.21: January 2004 response for a double power dip. There seems to be no response for the first of the two dips.

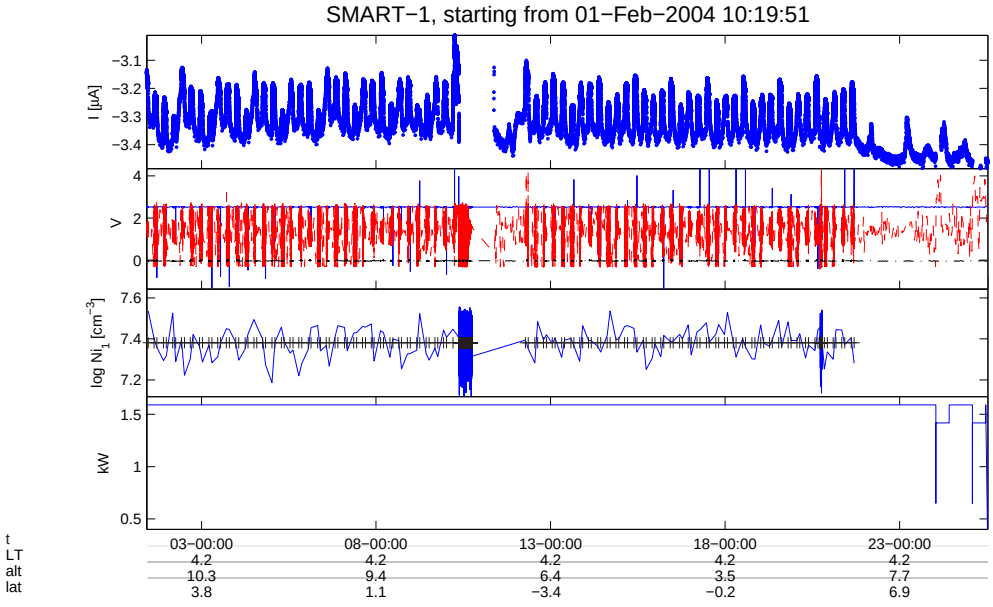


Figure 3.22: SPEDE plot of February 2004

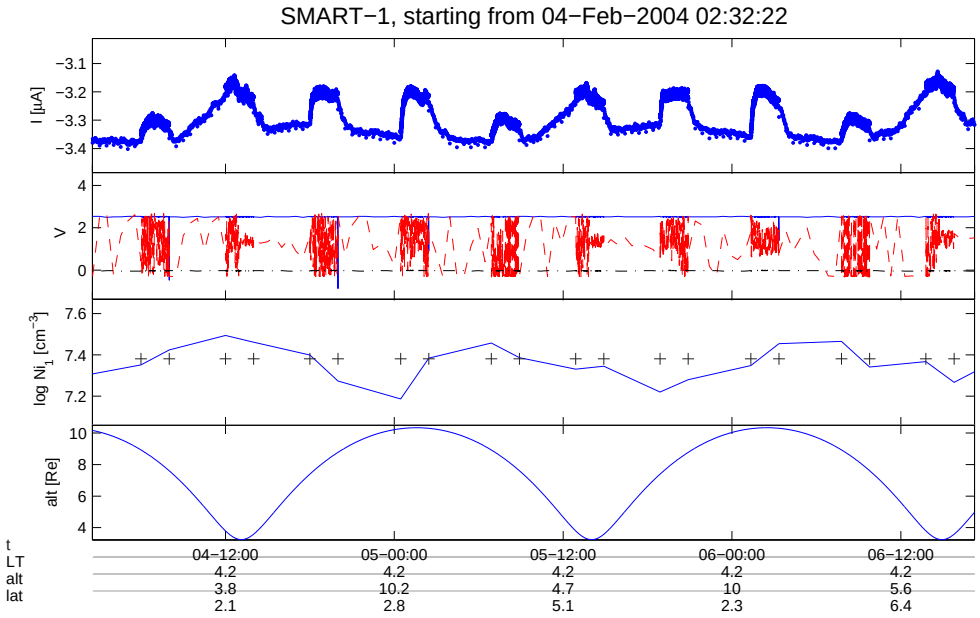


Figure 3.23: SPEDE plot of February 3th-6th 2004. Lowest panel shows the orbit altitude.

Chapter 4

Suggestions for Further Development

Different data types could be added from analysis products of EDPD SC and RPA instruments. Examples of these might be currents at different voltage levels (currently available only in form of quite uninformative sweep data) and the Retarding Potential Analyzer sweep derivate maximum, ie. the mode of energy distribution [CS05]. These could be added and saved by running the SPEDEgetDATA, also other data types and more processed data could be added if need be.

A 3D-model or drawings of the SMART-1 could be used with delivered orientation angles to give visibility and insolation levels of various critical instruments and spacecraft parts in order to analyze instrument outputs in more detail. After this a correlation study might resolve some of the unknowns in the SPEDE data behaviour.

Appendix A

Program M-files

The SPEDE analysis program consists of these m-files (on alphabetical order with brief descriptions).

EPDPivan.m	EPDP langmuir probe IV-analysis
EPDPlangmuir.m	EPDP langmuir IV curve plotting
EPDPlangmuirRPA.m	RPA sweep plotting
EPDPlangmuirSC.m	Solar Cell IV-curve plotting
EPDPreadLP.m	read EPDP Langmuir Probe data
EPDPreadQCM.m	read EPDP QCM data
EPDPreadRPA.m	read EPDP RPA data
EPDPreadSC.m	read EPDP Solar Cell data
SPEDE24hplot.m	make dayplots of current plot
SPEDE24hplotEPDP.m	make EPDP default dayplots
SPEDE24hplotSPEDE.m	make SPEDE default dayplots
SPEDE_Ni.m	Ion density from SPEDE LP sweep
SPEDEgetDATA.m	central script to read the data
SPEDEjpg.m	print picture to jpg
SPEDEkoodisto.m	data and code grid used by GUI
SPEDElangmuir.m	SPEDE langmuir IV curve plotting
SPEDElangmuirJPGall.m	make jpg's out of all SPEDE langmuir plots
SPEDEload.m	dialogue to load workspace
SPEDEmenublue.m	colors available menu-items blue

SPEDEorbit_xaxis.m	creates multiple x-axis
SPEDEorbit_xaxisKp.m	alternative choice of xtick labels
SPEDEplot.m	old and stripped plotting routine
SPEDEps.m	print picture to ps
SPEDEreadEF.m	read SPEDE Electric Field data
SPEDEreadHK.m	read SPEDE House Keeping data
SPEDEreadPD.m	read SPEDE Plasma Diagnostics data
SPEDEreadPVPC.m	read SPEDE PV/PC data
SPEDEshortcut.m	handle GUI plotting shortcut
SPEDEsubplot.m	handles the plotting, called by 'redraw'
SPEDEsubplotEPDP.m	predefined EPDP plot
SPEDEsubplotSPEDE.m	predefined SPEDE plot
SPEDEzoom.m	handles the zoom function
Status_to_num.m	changes status strings to numerical values
loadKP.m	loads Kp index values
plotPowerChanges.m	makes plots of all power change regions
remove_s.m	deletes outliers (of SPEDE langmuir sweep)
saveSpede.m	saving the workspace into .mat file
spede2.m	generates the GUI. START HERE!
subplotspace.m	helps in plotting, c Matlab file exchange
test_power.m	test for EP power time matching

Appendix B

Data Shortcut Codes

These are the codes for each data type to be used in the programs 'shortcut' function. Use this table to reference, understand or modify your existing shortcuts and to make new ones outside the program. The associated Matlab variable is typed after the shortcut number. For sweeps the actual thing plotted is an empty vector as only the points in time are plotted on the same axis with the other data. For these data the associated Matlab time vector is given instead of the plotted empty vector []. For some data, mainly those having incomprehensible program variable names, a more specific explanation is given after the variable name.

```
10  meas_EF
11  meas_EF2*1e6
12  VrefG
13  Vref1
14  Vref2
15  T2
16  log10(Ni_PD/1000000)
17  log10(Ni_PD2/1000000)
18  UTC_PD_kk1, Langmuir sweep spots for SPEDE 1
19  UTC_PD2_kk1, Langmuir sweep spots for SPEDE 2
20  SPEDEorb(:,7), latitude
21  SPEDEorb(:,6), longitude
```

```
22  SPEDEorb(:,8)/Re, altitude
23  Kp
24  LT
25  status
26  status_EF
27  status_EF2
28  status_PD
29  status_PD2
30  velocityEARTHms
40  UTC_LP, Langmuir sweep spots for EPDP
41  QCM_f/1000
42  UTC_SC, Solar Cell sweep spots
43  UTC_RPA, RPA sweep spots
44  QCM_T
45  EPDP_T
46  T_SC, solar cell temperature
50  Power
51  log10(EPDP_Ne/1000000)
52  log10(EPDP_Ni/1000000)
53  EPDP_Te, electron temperature from EPDP sweeps
54  EPDP_Vf, floating potential from EPDP sweeps
55  EPDP_Vp, plasma potential from EPDP sweeps via linefit
56  EPDP_Vp2, plasma potential from EPDP sweeps via derivation
57  Vcrp
```

Appendix C

IDL and SPICE

In this chapter we have listed the small IDL script used to get and save the orbital data. This is done at a one minutes resolution for one month at a time. The main spede2 program will then search and load these monthly orbital files. The script is found under name ajo.pro. To run it one must change the vv to the desired year and mm for the desired month (now showing February 2005). Also the filename towards the end of the file should be changed accordingly.

```
PRO AJO, longitude, latitude, dist, kaikki

longitude = 0;
latitude = 0;
dist = 0;
kaikki = [0,0,0,0,0,0,0,0];

vv = 2005;;ajetaan vuodeksi kerrallaan
mm=2

print, vv, mm

        case mm of
        1:      pp2 = 31
        2:      pp2 = 28
```

```
        3:      pp2 = 31
        4:      pp2 = 30
        5:      pp2 = 31
        6:      pp2 = 30
        7:      pp2 = 31
        8:      pp2 = 31
        9:      pp2 = 30
        10:     pp2 = 31
        11:     pp2 = 30
        12:     pp2 = 31
        endcase

for i = 1, pp2 do begin ;;paivat
for hh = 0, 23 do begin ;;tunnit
print, mm, i, hh
for minsat = 0, 59 do begin ;;minsat
sekat = 0 ;;myohemmin looppiin jos halutaan tarkempi reso?

        time = string(vv)+'-'+string(mm)+'-'+string(i)+ ...
               'T'+string(hh)+ ':'+string(minsat)+':'+string(sekat)

       spede_orb, time, distance, lon_deg, lat_deg
       kaikki = [kaikki,[vv, mm, i, hh, minsat, lon_deg, ...
                  lat_deg, distance]]

endfor ;minutes
endfor ;hours
endfor ;days

fname='/usr4/users/smerikal/SPICE/software/SPEDEorb_0205.dat'
OPENW,1,fname
PRINTF,1, kaikki ,
     FORMAT='(I4,1X,I2,1X,I2,1X,I2,1X,I2,1X,F0.3,1X,F0.3,1X,F0.2)'
```

```
CLOSE,1
END
```

The ajo.pro calls for spede_orb.pro, which is listed below:

```
PRO SPEDE_ORB, time, distance, lon_deg, lat_deg
;;
 kernelFileName = 'kernels_to_load'
 cspice_furnsh, kernelFileName

 ref = 'J2000'
 correction = 'LT+S'

 cspice_str2et, time, et

 ;; first step: calculate the vector (S1, SUN)
 cspice_spkezr, '-238',  et, ref, correction, 'SUN', ...
                s1_posvec, ltime

 ;; second step: calculate the vector (EARTH, SUN )
 cspice_spkezr, 'EARTH',  et, ref, correction, 'SUN', ...
                earth_posvec, ltime

 ;; third step: subtract vectors and get the distance
 cspice_vsubg, s1_posvec, earth_posvec, res_s1_earth
 distance = cspice_vnorm( res_s1_earth[0:2] )

 ;; calculate local time
 ;; sub s/c lat and lon
 cspice_subpt, "NEAR POINT", "EARTH", et,  "NONE", 'SMART1', ...
              point, altitude
 cspice_reclat, point, radius, lon, lat
 cspice_convrt, lon, 'radians', 'degrees', lon_deg
```

```
 cspice_convrt, lat, 'radians', 'degrees', lat_deg

 cspice_unload, kernelFileName

END
```

These files could relatively easily be adjusted to also save the solar angle, shadow percent of the booms and other information which is provided by continuously updated SPICE kernels. These routines require SPICE libraries [Act05].

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