User Guide to the **ASPOC** measurements in the Cluster Active Archive (CAA)

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1 Introduction

The instrument ASPOC (Active Spacecraft Potential Control) controls the electric potential of the Cluster spacecraft by means of an ion beam. This modification of the charge balance improves the plasma measurements on board. Beneficial effects have also been observed for the electric field measurements by double probes (EFW). Comprehensive knowledge about the status of the instruments including the ion beam current is necessary to correctly interpret spacecraft potential data.

This user guide provides an overview of the instrument modes and the parameters contained in the ASPOC data sets in the Cluster Active Archive. A few examples illustrate the relation between instrument modes and data. The document shows how to use the instrument datasets, what are the key science measurements and which datasets should be used.

2 Instrument Description

The ASPOC (Active Spacecraft Potential Control) instruments for the Cluster mission have been described by Torkar et al. (2001). The primary objective of ASPOC is to insure the effective and complete measurement of the ambient plasma distribution functions down to low energy.

With the exception of very rare eclipse time intervals the Cluster spacecraft are illuminated by the Sun, and photo-electrons are emitted from the surface. Throughout the Cluster orbit, i.e. outside the plasmasphere, emitted photo-electrons will dominate over collected plasma electrons. A balance between escaping and collected electrons is achieved at a positive potential forcing low energy photoelectrons to orbit back to the spacecraft, allowing only a fraction of the photoelectrons at higher energies to escape and be in current balance with collected plasma electrons. Ions can be neglected because of their low mobility compared to the electrons. The resulting uncontrolled potentials may reach +50 V and more in regions of the magnetosphere with tenuous plasma.

In order to control the electrical potential of the spacecraft, the ASPOC instruments emit a beam of positive indium ions (115 amu) at energies of about 6 to 9 keV and currents up to about 30 μA. Typical currents applied in the mission were between 10 and 20 μA. The emission of positive charges from the spacecraft balances the excess of charge accumulating on the vehicle from interactions with the environment. By adjusting the positive emission current, the spacecraft potential can thus be adjusted to single-digit positive voltages. As a result of the equilibrium between the relevant currents of photo-electrons generated at the spacecraft surface, plasma electrons from the environment, and the ASPOC ion beam current, the spacecraft potential will be clamped to a potential determined by a current balance between ASPOC-generated ions on the one hand and escaping photoelectrons minus collected ambient electrons on the other hand. In a tenuous plasma the latter term can be neglected.

The resulting improvement of both particle and electric field measurements is most effective in low plasma density environments and boundaries thereof. In these environments the equilibrium potential of the space-craft is not only strongly fluctuating together with the variations of plasma density, but also the absolute value of the potential easily reaches tens of volts positive. As a consequence, the bulk of photo-electrons will return to the surface and the plasma electron detectors, where the resulting high count rates let the micro-channel plates age at a faster rate. The energies and trajectories of plasma electrons and ions are modified in the potential well around the spacecraft, thereby complicating the interpretation of the distribution functions and the calculation of plasma moments.

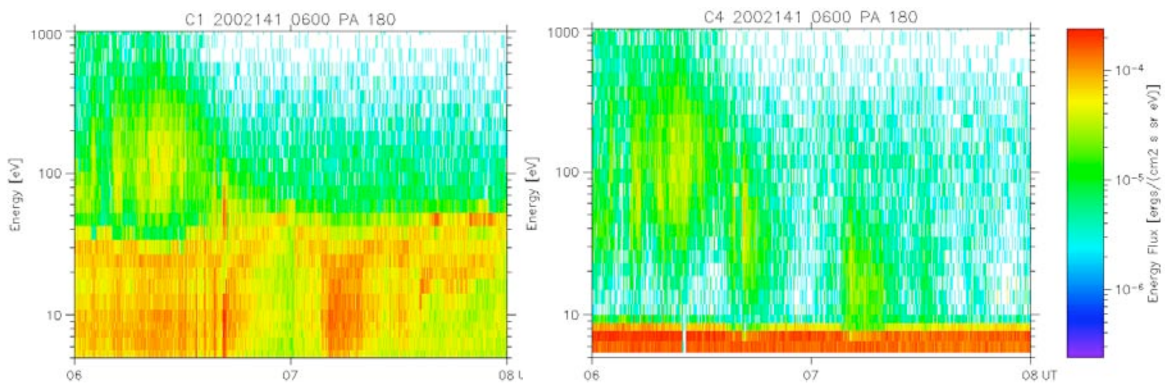

Fig. 1. Energy-time spectrograms of field-aligned electrons from the PEACE-LEEA sensors of spacecraft 1 (left) and spacecraft 4 (right) plotted as function of time on May 21, 2002, from 06 to 08 UT.

The improvement of the electron measurements by a controlled spacecraft potential is illustrated in Fig. 1 adapted from Torkar et al. (2005). It shows energy-time spectrograms of field-aligned electrons measured by the PEACE-LEEA sensors (for an instrument description see Szita et al., 2001) of Spacecraft 1 (panel a) and 4 (panel b) over a two-hour time interval starting at 06 UT on May 21, 2002. The electron features in the 10-100 eV decade clearly visible on spacecraft 4 - where ASPOC reduced the potential to ~8 V - are not discernible on spacecraft 1, where the uncontrolled potential peaked at 47 V. The spacecraft potential is measured by the EFW instrument (Gustafsson et al., 1997, 2001). Its probes are controlled to stay within 1-2 V relative to the ambient plasma and thus provide a reference for the measurement.

A reduction of the spacecraft potential also helps to avoid wake artefacts in electric field measurements by the double probes, which may occur in cold, streaming plasma, e.g., polar wind (Engwall et al., 2006). Under similar conditions, the ion spectrometer CIS (Rème et al., 2001) could detect cold ion beams (H+ and O+) only while ASPOC was operating.

As the photo-emission is fairly stable, the potential of a spacecraft (without control) reflects the variation of the plasma electron current and thereby images the electron density and temperature. As the temperature effect is relatively small, the uncontrolled spacecraft potential is often used as an estimator for plasma density. However, the introduction of an artificial ion current for control purposes changes the relationship dramatically. Under the influence of a constant artificial ion beam current, the controlled spacecraft behaves like a strongly biased plasma probe with rather small residual variations of the potential.

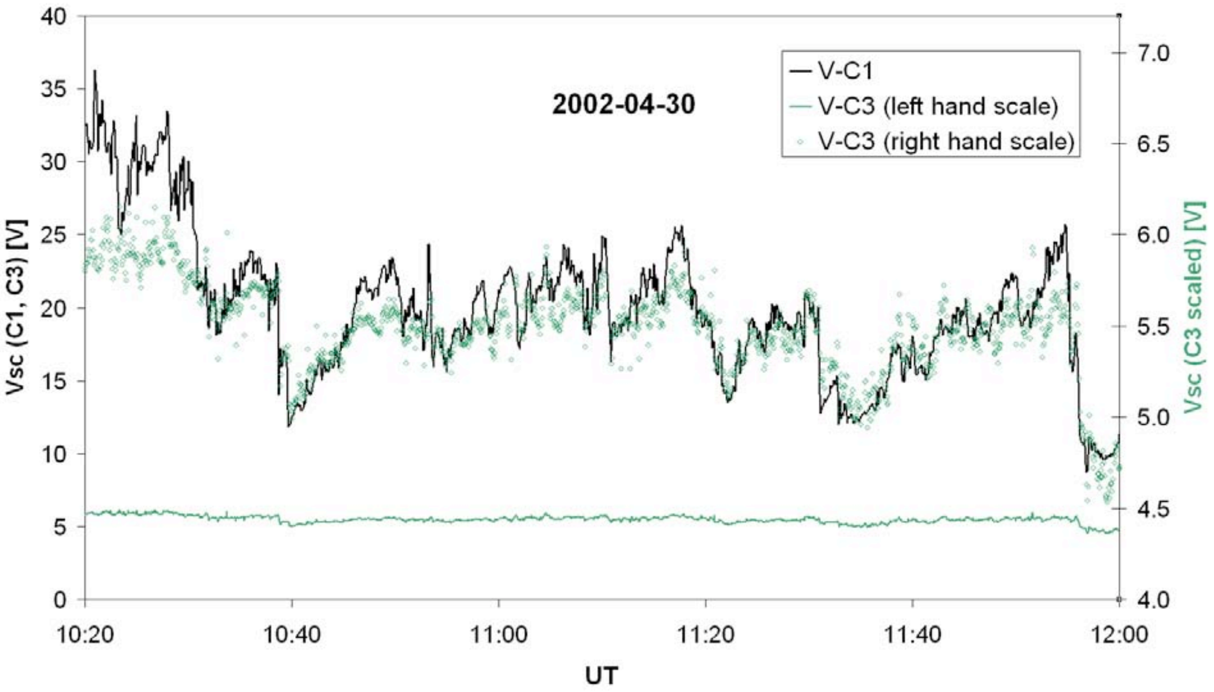

Fig. 2. Spacecraft potential (raw potential between the probes and the spacecraft body) measured by EFW (Electric Fields and Waves, Gustafsson et al., 2001) on spacecraft 1 (black, scale at the right) and 3 (green, scale at the left) on April 30, 2002, from 10:20 to 12:00 UT.

As illustrated in Fig. 2, a good correlation between the uncontrolled potential (spacecraft 1, black line, scale on the left hand side) and the con-trolled potential (here represented by spacecraft 3, green line and dots) may still exist. The potential of spacecraft 3 is shown in two different ways. The full, green line refers to the common scale with spacecraft 1 on the left hand side and demonstrates the significant reduction of the potential. The same data set is also shown by the green dots for which the right hand scale is valid. The good correlation between the residual variations of the controlled potential on spacecraft 3 with the uncontrolled values on spacecraft 1 is obvious. Thus, by inserting the ASPOC ion current into the current balance equation for the controlled spacecraft one can deduce the uncontrolled potential and use it for density estimations as usual.

3 Instrument Operations

3.1 Ion emitters

The ion emitters are liquid metal ion sources using indium as charge material. A needle is mounted in a reservoir with indium, which has to be elevated to operational temperature (well above the melting point of indium at 156ºC by an attached small heater. The melting process is initiated by command and takes about 12 to 20 minutes. When the specified temperature has been reached, high voltage is turned on and ramped up until the field emission process around the liquid indium at the tip ignites and an ion beam is generated. As soon as the ion beam appears, the high voltage supply is switched into a current controlled mode where the emission current is being set, while the extraction voltage adjusts itself to the conditions of the emitter.

The emitters are operated one at a time. For lifetime and redundancy, each instrument holds eight emitters, arranged in two “modules” with four emitters each. All emitters within a module are connected to a single high voltage circuit. The selection of the active emitter is made by heating one of them (the tip curvature of cold emitters with solid indium is not suitable for field emission).

3.2 Currents in the emitter system

The behaviour of the ion beam current is better understood with some knowledge of the currents flowing in the emitter system. At first, there is the current of the emitted ion beam. This current is referred to as ion cur-rent, beam current, or emission current. It continues through the ambient plasma and is closed by other currents to the spacecraft surface, particularly the photoemission current. ASPOC ions returning to the spacecraft can be totally neglected even if the ion beam is emitted perpendicular to the magnetic field. Secondly, there is the total current delivered by the high voltage supply to the emitter. This current includes the beam current and internal loss currents (e.g. the current to the extraction and beam focusing electrodes), and may therefore be larger than the beam current. There are two major types of loss currents: currents from ions hitting the extractor electrode, and leakage currents through insulators. The percent-age of extractor electrode currents with regard to the total current is small (0 to 20%) for small to medium currents and may increase to 30 to 50% for currents of about 50 μA.

The typical emission currents applied on Cluster range between 10 and 16 μA. They set an upper limit to the spacecraft potential on the order of 6 to 8 V. The emission current of an emitter may be increased to maximum current over a short period (between 30 seconds and a few minutes) as a precaution to remove any contamination from the emitter, thereby ensuring that the operating voltage remains within operational limits. This procedure is called "cleaning".

3.3 Instrument modes

The most widely used active mode of the instrument is the "constant total current mode" (ITOT). It sets a constant output current of the high voltage unit, which includes any losses inside the lens system. Experience has shown that the resulting emission of an almost constant ion current fulfils all requirements for spacecraft potential control in the magnetosphere and the solar wind even without on-board feedback from measurements of the spacecraft potential.

In "constant ion current mode" (IION) the processor of the instrument reads the monitor of the outgoing beam current and adjusts the output cur-rent of the high voltage supply to compensate for any losses in the system. This mode has been used during commissioning only.

In the two available, so-called feedback modes, a measurement of the spacecraft potential is supplied to ASPOC by either the electric field experiment (EFW) or the electron analyser (PEACE) and this information is then used to adjust the beam current in order to maintain a constant value of the potential in a closed-loop scheme. This mode is called feedback mode with EFW (mode FEFW) or feedback mode with PEACE (mode FPEA). The measurements of the spacecraft potential are updated once every spin and sent to ASPOC via dedicated serial, digital inter-experiment links. The mode FEFW has been tested successfully during commissioning. Unfortunately, active soundings of the WHISPER instrument cause spikes in the potential information transmitted on board. The control software could not handle these spikes, so that this feedback mode could not be used in the nominal mission. The feedback mode with PEACE suffered from the difficulty to provide a reliable potential estimator from the electron spectra onboard, and was not used in the mission at all.

In standby mode (STDB) both the emitters and their heaters are turned off. The standby mode is also the safe mode of the instrument, to which it returns autonomously under certain error conditions. The transition into standby mode also clears all error flags and the emitter selection, and disables high voltage and the heaters.

In order to reduce the time before emission starts, a “hot standby” mode (HOTS) keeps the indium in a liquid state. This mode can be used to interrupt the ion emission by command, without change of modes or emitters before and after the break. The re-ignition time is reduced to the time required to sweep the high voltage (less than a minute).

A “test and commissioning” mode (T&C) varies the total ion current in steps of 8 or 16 s with 2 or 4 μA current increments. This mode has been used occasionally to establish the current-voltage characteristics of the spacecraft.

A technical mode (TECH) is available for low-level commanding during commissioning and re-commissioning of emitters.

Start-up (STUP) is a state of the instrument at the beginning of an active mode when the emitter is being warmed up and ion emission has not yet started. Depending on ambient temperature and emitter condition it takes about 12 to 20 minutes to reach a temperature inside the emitters which is sufficient to ignite the ion beam. Within this period the "instrument mode" reported in telemetry is already the commanded target mode, although there is no ion emission yet.

4 Measurement Calibration and Processing procedures

The quality of the datasets is not affected by any calibration and/or processing details of the measurements. Caveats are depending on the status and quality of the ion emission only. The respective information is given in the CAVEATS dataset which is described briefly in Table 1 of section 5.

5 Key Science Measurements and Datasets

The key measurement in the ASPOC datasets is the emitted beam current (dataset IONC). Table 1 lists the ASPOC Datasets available in the Cluster Active Archive. All data sets are Cluster Exchange Format (CEF) files, except the textual caveat description.

Table 1. ASPOC datasets

Product	Description
IONC	ASPOC ion beam current at a sampling interval of 0.5 s.
IONS	Snapshots (samples of 8.25 s duration collected every 128.8 s) of the ion beam current with a sampling interval of ~0.033 s. Suitable to check current fluctuations in the beam and to resolve the current profile during the ignition or shut-down of an ion emitter.
STAT	Comprehensive status information of the instrument at 5.15 s resolution (10.3 s for some parameters). • Operating mode, including emitter start-up status and cleaning: In both of these states the beam current deviates significantly from the nominal current. • Emitter identification and emitter module identification: Each instrument carries eight emitters bundled into two modules with a common high voltage system within a module. Both emitters and modules may exhibit individual characteristics and performance, which may have an effect on the value and temporal behaviour of the beam current. • Anomaly flags: These flags give the reason for an anomaly, for example failure of ignition of an emitter. • Ion beam energy: The voltage applied to the emitter is equivalent to the energy of the ions in the beam.

STAT (continued)	• Total ion source current: The current delivered by the high voltage supply into the emitter will be higher than the emitted current if internal losses are present. • Heater current: The current drawn by the heater element associated with an emitter. • Heater voltage: The voltage applied to the heater element associated with an emitter. Voltage and current together can be used to calculate not only the electrical power but also the temperature of the heater element. From this temperature, the temperature of the emitter tip can be derived. • Temperature of the ion source module: This parameter contains the ambient temperature of the emitter module. The temperature of the emitter tip shows a strong dependence on the heater temperature, but also some influence of this ion source module temperature. • Raw spacecraft potential received on board from EFW: This parameter mirrors the spacecraft potential data delivered by the instrument EFW to ASPOC on board the spacecraft. It differs from the EFW data product in the archive with respect to timing.
CMDH	Command history with time stamps according to on-board execution time by the instrument. The execution delay may reach one minute. Included parameters are the command code, the command counter, command mnemonic, description, and parameter (if any).
CAVEATS	Information on the status and quality of the ion emission (see the description of quality levels). Time spans correlate with commands to change the operational mode or the value of the current. • Mean quality level during time span • Minimum quality level during time span • Maximum quality level during time span • Comment; a textual description associated with the average quality level value.
ACTIVE	Contains the time spans when ASPOC is switched on and is emitting a significant ion current (> 1 μA). Useful for quick checks whether ASPOC was operational.

The caveat information consists of an automatically generated part (CEF) and a manually generated part (text) added after inspection of the data produced in the batch process. The automatically generated caveats shall help the user to assess the quality. The production software derives a quality parameter from the total current consumed by the ion emitter and the emitted ion current.

In the typical mode of operation a constant current is applied to the ion emitters. If internal loss currents can be neglected, the emitted ion current is also constant and the resulting spacecraft potential has the best stability. In the presence of loss currents, the emitted ion current and with it the spacecraft potential will start to fluctuate. Table 2 summarises the definition of the quality levels. There are new entries whenever the instrument mode changes, or when the commanded emission current changes.

Table 2. Quality level definition

Quality Flag	Condition	Ion Emission Quality Definition
1	$I_{beam}/I_{total} > 0.97$	Excellent
2	$0.92 < I_{beam}/I_{total} \leq 0.97$	Good, almost completely stable
3	$0.75 < I_{beam}/I_{total} \leq 0.92$	Moderate fluctuations
4	$0.30 < I_{beam}/I_{total} \leq 0.75$	Substantial fluctuations
5	$0.00 < I_{beam}/I_{total} \leq 0.30$	Severe variations
8	$I_{total} \geq 20$ µA AND $I_{beam}/I_{total} \geq 0.50$	Cleaning
9	$I_{beam} = 0.0$	No emission

6 Recommendations

The datasets can be used as is. A prioritisation of particular datasets over others is neither foreseen nor recommended, although the key information is reflected in the ion beam current status (IONC dataset) and the related spacecraft potential received from EFW (STAT dataset).

7 Examples and Applications

No specific software is required to use the data sets. However, visualisation software in IDL language originally developed for the validation of the data products is available. It allows to browse through a set of CEF files, either uncompressed or in gzip. Check boxes allow to select certain parameters. Plot options and scales can be set automatically or interactively. The plots presented in this section have been generated by this tool.

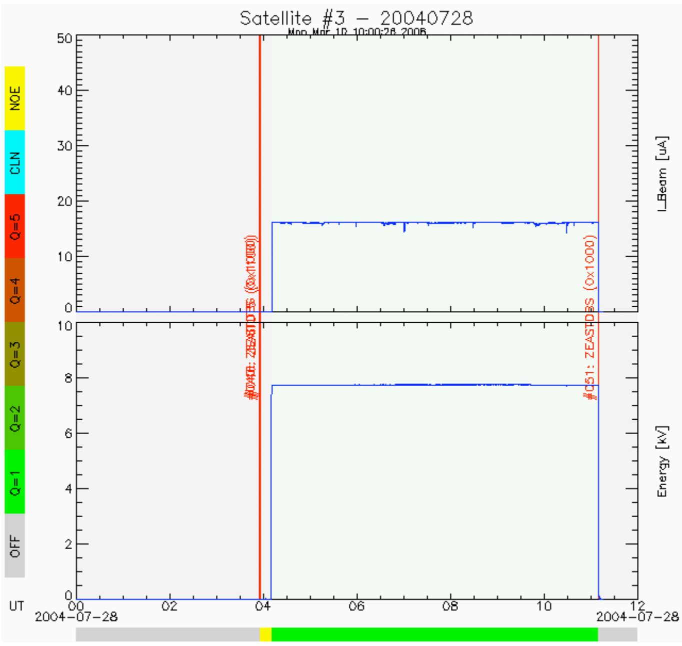

Fig. 3. ASPOC data set visualisation with beam current, beam energy, data quality, and commands.

Fig. 3 shows beam current and voltage in the top and bottom panel, respectively, over a 12-hour time interval for spacecraft 3. The colour bar at the bottom indicates the quality flag, which is one (excellent) for this operational interval of about 7 hours. The commands to enter into active mode have been sent shortly before 04 UT (red vertical lines). It takes about 15 minutes (interval indicated by the yellow status bar) until the emitter is hot and ion emission starts. The time interval contained in the respective entry in the ACTIVE data set would only cover the time interval of the green status bar.

Fig. 4 shows (from top to bottom) for the same time interval the beam current, total current, and spacecraft potential (as transmitted on board from EFW to ASPOC). Noteworthy is the "bite-out" of the beam current at 18:30 UT, due to a suddenly appearing and later disappearing leakage cur-rent inside the emitter. Although the beam current decreases by about 30%, the spacecraft potential hardly shows any reaction. This shows that variations of the beam current should be taken into account for accurate studies related to spacecraft potential, but do not generally deteriorate the control of the spacecraft potential.

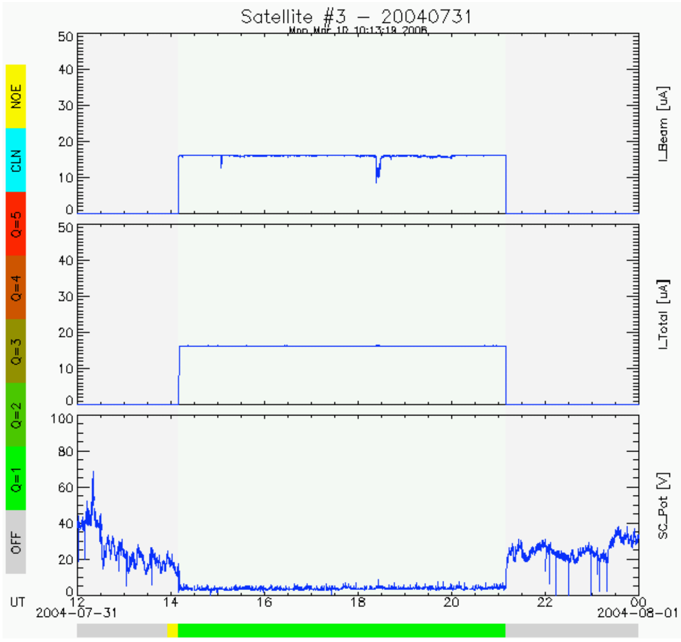

Fig. 4. ASPOC data set visualisation with beam current, total current, and spacecraft potential.

Finally, Fig. 5 illustrates an application of the beam current snapshot parameter (IONS) at 33 ms resolution. The plotted interval covers 15 s around a beam turn-on. The top panel contains the standard beam current parameter (IION) which cannot fully resolve the variation of the beam cur-rent, whereas the snapshot reflects the variations very accurately, which is confirmed by the analogous variation of the spacecraft potential (bottom panel) taken from the EFW data set C3_CP_EFW_L2_P.

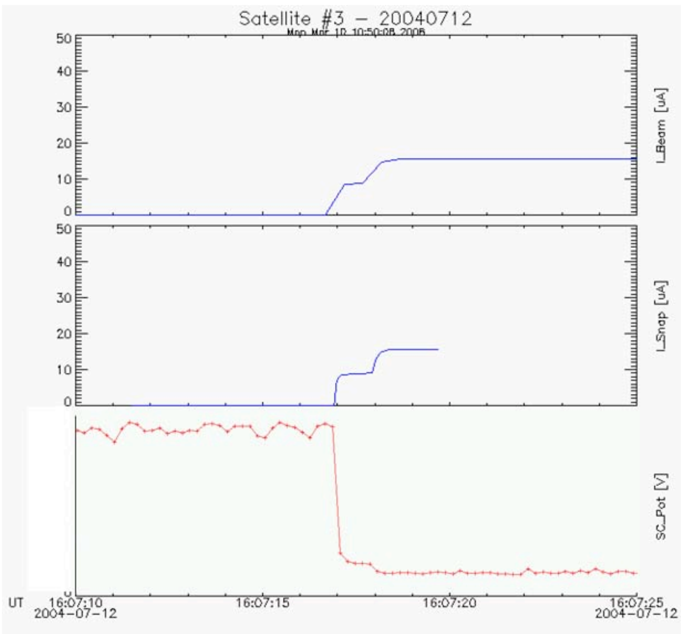

Fig. 5. Example of ASPOC snapshot data set with corresponding variation of the spacecraft potential.

8 References

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