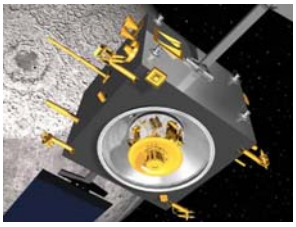
Observation of SMART-1 plume plasma environment with the EPDP plasma diagnostic package and EPDP future activities

TAS-I contribution to the 14° SPINE Meeting
ESA/ESTEC 13-14 November 2008

14° SPINE MEETING

EPDP onboard SMART-1



Objective:

- **Electric Propulsion monitoring**

EPDP: Plasma Diagnostic Package instrument

- **Langmuir Probe and Retarding Potential Analyzer close to the plasma engine outlet.**
- **Plasma density, temperature, and spacecraft potential derived quantities**
- **Thrust on and off transient recoding using LP at constant voltage**
- **Coordinated operations with SPEDE instrument**

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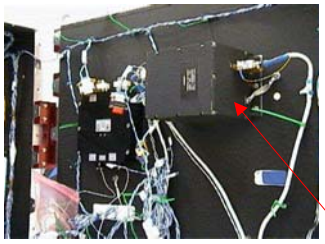
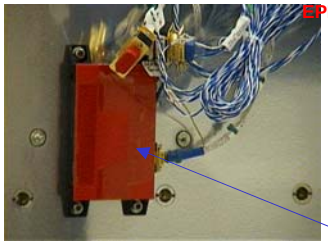
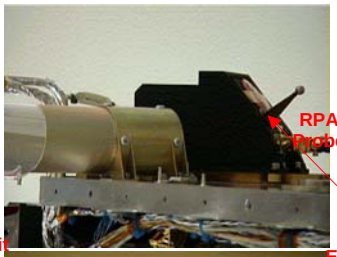
EPDP onboard SMART-1



EPDP IEA Unit

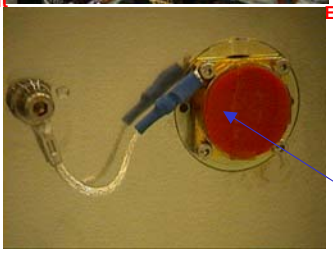


EPDP Solar Cell



RPA Probe

EPDP PPA Unit



EPDP QCM

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EPDP onboard SMART-1

- **LEOP**
  - **Commissioning**
  - **In-Flight calibration (with SPEDE) in dense cold plasma**
- **Initial thrust phase**
  - **EP monitoring, to cope with limited time for thrusters off**
- **Cruise Moon Capture and Moon phase**
  - **EP monitoring**

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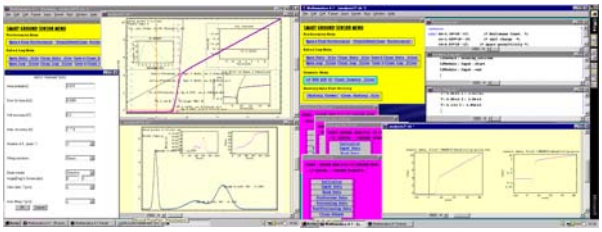
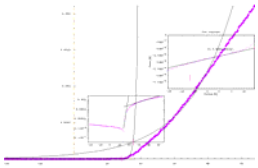
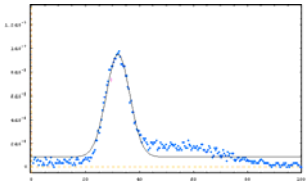
EPDP onboard SMART-1



Sw tool for data post-processing:
-Langmuir probe analysis: basic Langmuir thory with corrections for ion models
-RPA data analysis and energy spectra derivation
- database functions

Sw tool for data retrieving and first visualisation
-science and H/K data extraction translation & calibration
-data I/F formatting for SW analysis tool





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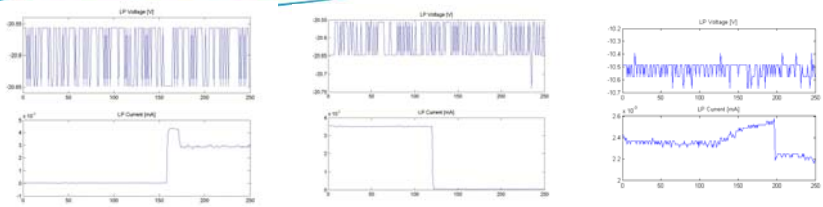
EPDP onboard SMART-1

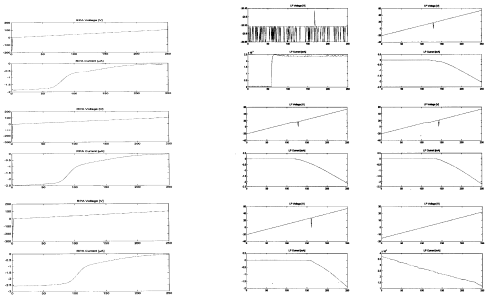


Transient monitoring: Power On and OFF by LP ion / electron current at fixed voltage

THRUSTER PULSE REF.

ON: ~ 2003-10-10 T 17:30:29
OFF: ~ 2003-10-11 T 02:45:08

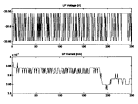
• Shift in the RPA Ei peak with time seen systematically during EP pulses



THRUSTER PULSE REF.

ON: ~ 2003-10-10 T 17:30:29
OFF: ~ 2003-10-11 T 02:45:08

• Shift in the LP Floating potential with time seen systematically during EP pulses



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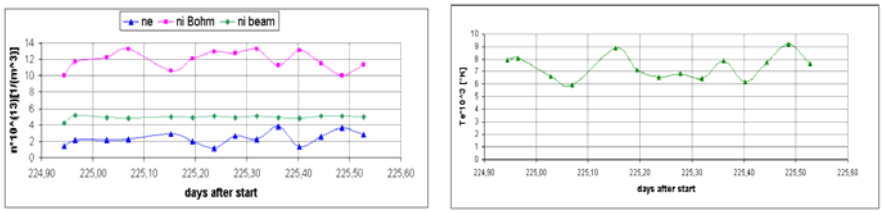
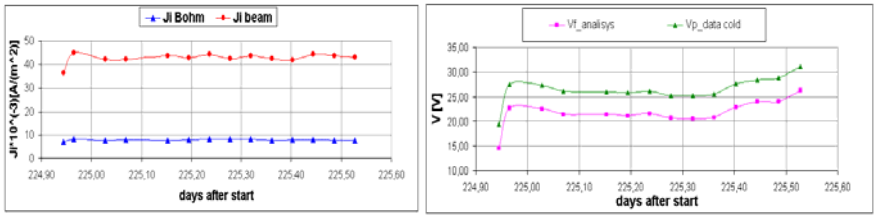
EPDP onboard SMART-1



LP ion and electron density analysis and electron temperature (09/05/2004-10/05/2004)



LP ion current density and LP potentials (09/05/2004-10/05/2004)

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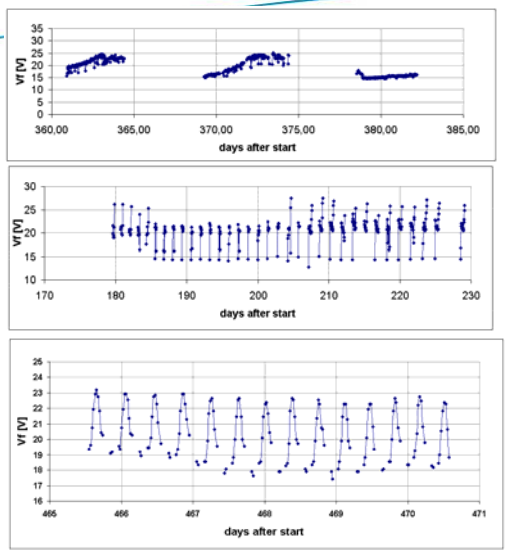

LP Vf time trends analysis

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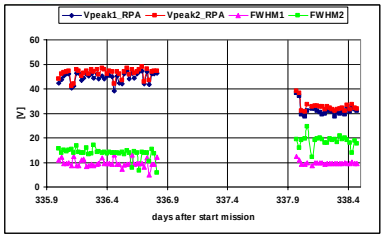
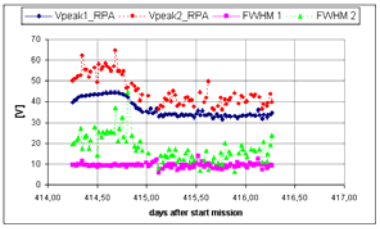
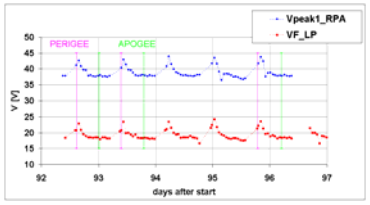
EPDP onboard SMART-1

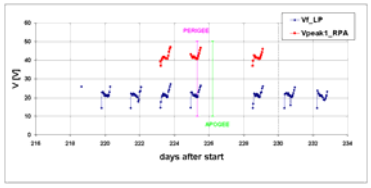




RPA energy spectrum trends analysis



LP floating potential and RPA first peak potential from 29/12/2003 to 02/01/2004



floating potential and RPA first peak potential from 08/05/2004 to 14/05/2004

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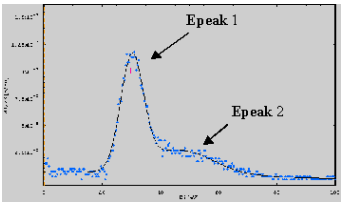
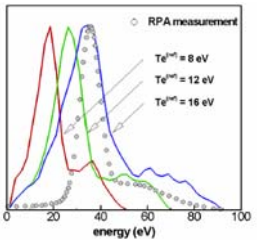
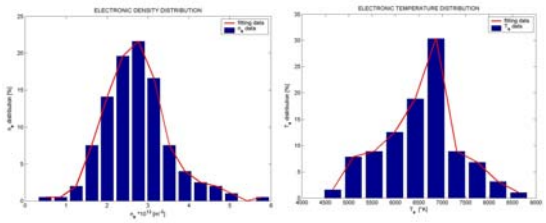
EPDP data correlation and verification



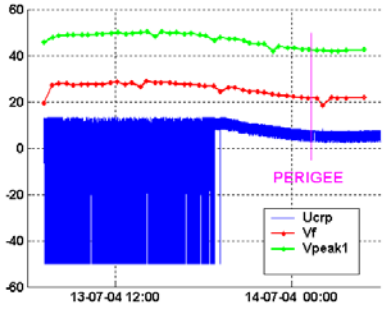
Examples of comparison between PIC simulations of the expected energy spectra and RPA experimental data are reported here below. The simulations, were realized by two different simulation groups: groups from ALTA and groups from ARC and show good agreement. The two groups use two different simulation codes able to simulate charge exchange processes. These work have been performed under the framework of various plasma group meetings held in ESTEC-ESA

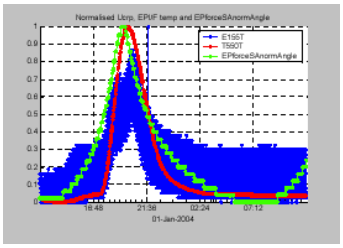




EPDP data correlation and verification

From detailed studies held in ESTEC it has been found that the orbital changes in the Ucrp data is correlated with the rotation of solar array it is then a logic consequence to consider that this rotation is the cause of changes on the LP and RPA characteristic potentials too. In the next figure the angle between the thrust vector generated by EP (opposite to the plume vector) and the vector normal to the cell side of the solar array panels (EpforceSAnormal) fits reasonably well with the Ucrp curve





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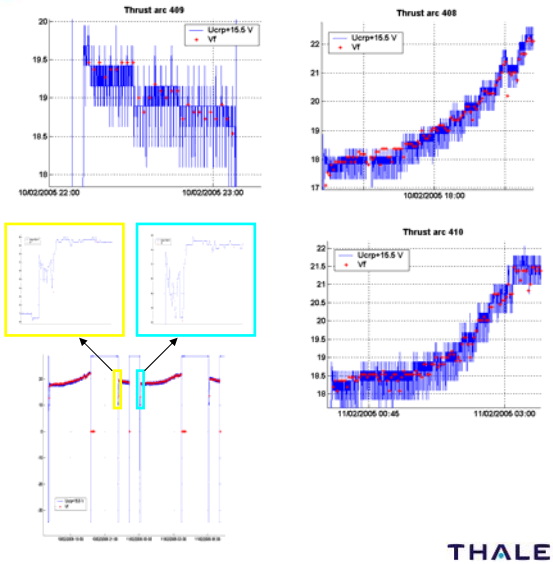
EPDP data correlation and verification

The Ucrp parameter is found to vary approximately in discrete steps following rotation of the Solar Array (SA).; the same trends can be seen for the Vf parameter; in the plots the Ucrp shifted by a constant value of 15.5 Volts and the Vf parameters are shown well over-imposed demonstrating the same trends and discrete step variations with time



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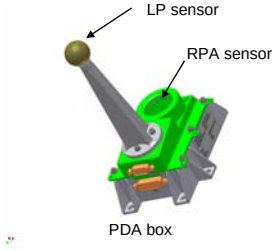
EPDP ongoing activities: LISA PF

EPDP for LISA PF is an instrument devoted to the monitoring of the Electric Propulsion System on board LISA PF

OBJECTIVES:
-Monitoring of the plasma environment generated by the FEEPs thruster and their related neutralisers (also under development at TAS-I) through the use of LP and RPA sensors.
-Estimation of the S/C local Plasma potential through tracking of the LP floating potential.
-Monitoring of S/C surface contamination effects through QCM data analysis

The instrument takes fully into account SMART-1 EPDP design heritage. It is composed by three boxes and their connecting harness:
PDA: Plasma Diagnostic Assembly
PCU: Power & Controlu Unit
QCM Quartz Crystal Microbalance
Main Operational Modes:
-LP data acquisitions (-200÷200V)
-RPA data acquisitions (0÷450V)
-QCM data acquisitions



PDA box

QCM box

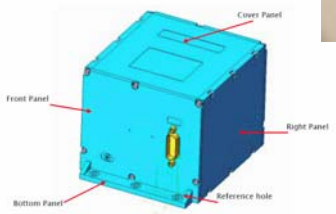


Fig. 3-1 PCU 3D model design

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EPDP ongoing activities: LISA PF

- Development status
  - PDR and CDR reviews succesfully achieved;
  - Detailed design and analysis and Breadboarding achieved;
  - PFM model under construction
    - Mechanical parts, LP / RPA sensors and QCM already realised/procured;
    - Flight Electronic boards in the final phase of construction/testing;
    - Dry Run and start of ProtoQualification activities expected within the end of the year.

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EPDP possible future activities

The following activities have been considered for future development and applications of EPDP

Step 1: Development of a Modular EPDP (M-EPDP) at EE-B level within GSTP-4 contractual frame

Step 2: Validate the M-EPDP with an Electric Thruster selected by ESA within an ARTES contractual frame

Step 3: Design finalization and qualification of the M-EPDP to future TLC satellite platforms (e.g. Alphabus and /or Small GEO)

Step 4: Perform the in-flight mission collecting the necessary experimental data for the validation of plasma interaction models already developed.

In parallel to the main points of the road map, the following developments are envisaged

1) assess the M-EPDP operation in conjunction with the ACSS (in case TAS-I will be awarded) for the complete characterization of the Space Charging Detection and Active Prevention Process

1) Assess possible M-EPDP modifications for the characterization of the Micro Ion engines (e.g. for Proba-3 mission)

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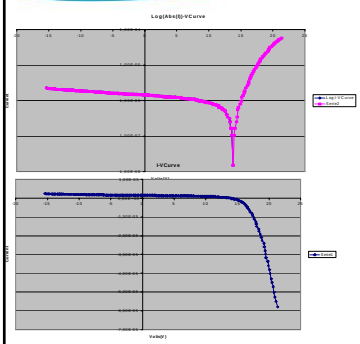
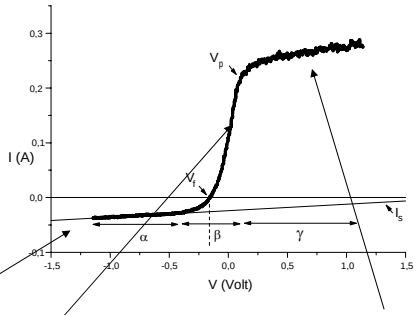
EPDP numerical modelling





α region

$$I_s \approx \frac{A_p}{4} e n_i c_c \left(1 + \frac{e|V - V_p|}{E_{beam}}\right)$$

$$c_b = \sqrt{\frac{2E_{beam}}{m_i}}$$

β region

$$V_p = V_f - \frac{kT_e}{e} Ln\left[I_s / I_e\right]$$

$$I_e = eA_p \frac{1}{4} n_e \bar{v}_e \exp(e(V - V_p)/kT_e)$$

$$I_e(V_p) = \frac{1}{4} eA_p n_e \bar{v}_e = eA_p n_e \sqrt{\frac{kT_e}{2\pi m_e}}$$

$$n_e = \frac{4I_e(V_p)}{eA_p \bar{v}_e}$$

γ region

$$I_e = \frac{1}{4} A_p e n_e \bar{v}_e \left(1 + \frac{e(V - Vp)}{kT_e}\right)$$

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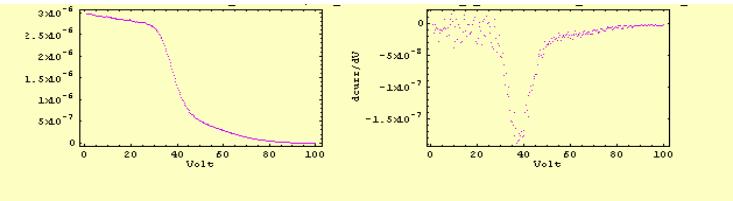
EPDP numerical modelling



Parameter	Min. Value	Max. Value
Initial voltage	0	416.7
Voltage step (10 bit)	0.203	208.3
Number of steps	0	250

RPA voltage ramp

$$f(E) = C\frac{dI_{coll}(V_3)}{dV_3}$$

EPDP numerical modelling: needs

- Real LP and RPA numerical modeling
  - -2D/3D numerical modeling;
  - -improved electron and ion models with arbitrary EEDF/IEDF and real plasma effects like collisions,reflections, ionisation, double charged etc..;
  - -RPA sheath effects on grid textures
- S/C simulation to correlate local to environmental plasma parameters
  - Thruster/neutraliser modelling
  - S/C modelling
  - CEX modeling
  - Virtual probe simulation for I/F with detailed LP/RPA simulations

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Conclusions

- EPDP instrument has demonstrated to be a powerful tool for investigating local plasma parameters close to S/C expecially in presence of Electric thrusters and/or active plasma generators
- EPDP design experience started since ARTEMIS mission and has now a consolidated heritage even if it has been tailored each time to specific program needs.
- Activities are on-going for the LISA PF mission where FEEP thrusters will be used.
- Foreseen activities are expected in the frame of the development of a more modular and versatile instrument called m-EPDP for next missions such as SMALL GEO, Alphabus/Alphasat, Proba-3 and possibly BEPI COLOMBO.
- Possible improvements are also considered for environmental plasma monitoring expecially for low orbit such as LEO and LEO POLAR ones.

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