SLP: the Sweeping Langmuir Probe instrument

S. Ranvier[1], M. Anciaux[1], J. De Keyser[1], J.P. Lebreton[2]

[1] Royal Belgian Institute for Space Aeronomy (BIRA-IASB), Belgium
[2] Laboratoire de Physique et Chimie de l'Environnement et de l'Espace (LPC2E), France

sylvain.ranvier@aeronomie.be

D3S Workshop, 23-24 October 2019, ESOC, Darmstadt, Germany

KONINKLIJK BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT ROYAL D'AERONOMIE SPATIALE DE BELGIQUE ROYAL BELGIAN INSTITUTE OF SPACE AERONOMY KONINKLIJK BELGISCH INSTITUUT VOOR RUIMTE-AERONOMIE INSTITUT ROYAL D'AERONOMIE SPATIALE DE BELGIQUE ROYAL BELGIAN INSTITUTE OF SPACE AERONOMY KONINKLIJ

Outline

- PICASSO mission and platform
- Scientific objectives of SLP
- Measurement principle
- Measurement modes
- S/C charging
- HW: Probes, electronics, integration
- Functional test in plasma chamber

PICASSO mission and platform

Payload

VISION (Visible Spectral Imager for Occultation and Nightglow):
Visible and near-infrared hyper-spectral imager
HW from VTT, Finland; SW from BIRA-IASB

Objectives:

- Polar and mid-latitude stratospheric ozone vertical profile retrieval
- Upper atmosphere temperature profiling based on the Sun refractive flattening

SLP (Sweeping Langmuir Probe):
Four channel Langmuir probe instrument
Fully developed at BIRA-IASB

Measurements:

- Plasma density, electron temperature and spacecraft potential retrieval

PICASSO mission and platform

Orbit:
Polar, altitude: 550 km

Expected orbital lifetime: 2 years

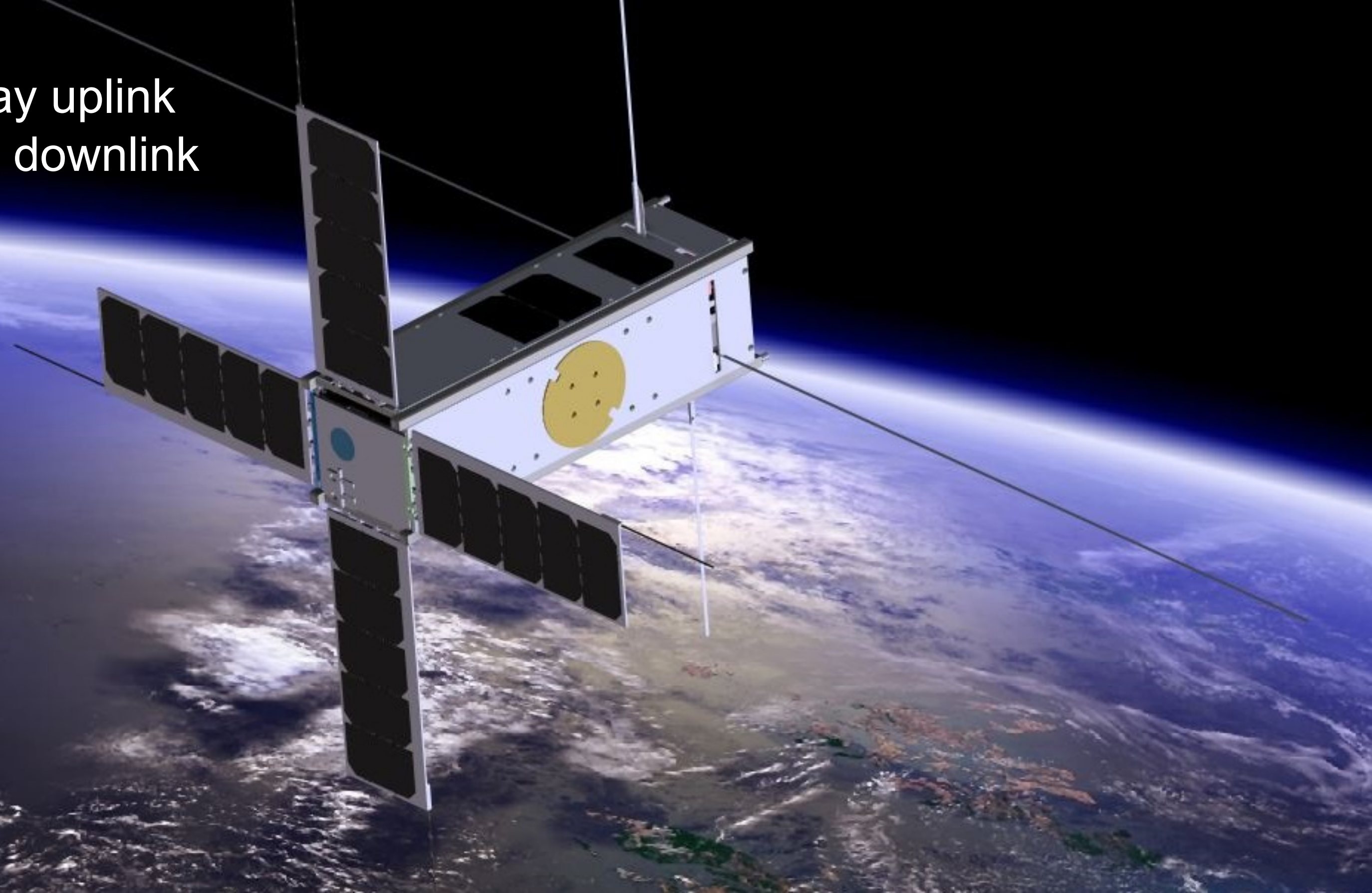
Launch: Q3 2019

Platform:
3U CubeSat (340.5 x 100 x 100 mm)
1U for payload

	Minimum (> 95% probability)	Maximum (> 95% probability)
Plasma density ($\#/m^3$)	10^8 (10^9)	10^{13} (5×10^{12})
Electron temperature (K)	600 (700)	10 000 (5 000)
Debye length (m)	5.4e-4 (8.2e-4)	0.69 (0.15)

PICASSO mission and platform

- Four deployable solar panels
- Power generation (ave.): 8,7W , power consumption (ave.): 8.25W
- Two on-board computers (OBC and PLC)
- High performance ADCS: pointing accuracy~ 1° (knowledge: 0.2°)
- Dimensions: 340.5 x 100 x 100 mm
- Mass: 3,9 kg
- UHF/VHF: 400 kB/day uplink
- S-band: 100 MB/day downlink

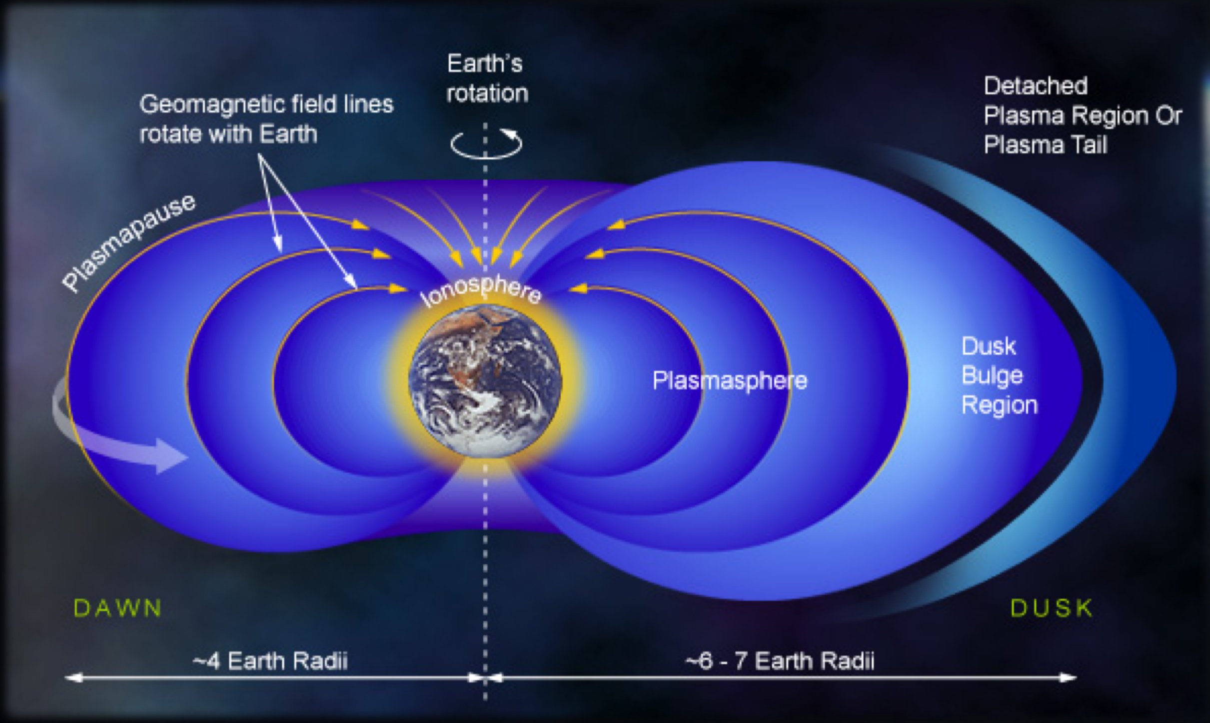


SLP: scientific objectives

Ionosphere-plasmasphere coupling

Compare density and temperature data from SLP with data obtained along magnetic field lines at different altitudes from other data sources

⇒ study field-aligned density distribution and temperature effects



SLP: scientific objectives cont.

Aurora structures

• SLP measures density and temperature only at ~550 km altitude ⇒ need supplementary data: simultaneous measurements from other spacecraft on roughly the same field line (both in low or high Earth orbit, e.g. Cluster), EISCAT radar data, or ALIS data (ionospheric optical tomography).

• PICASSO data : in situ truth to EISCAT data interpretation algorithms

• EISCAT data : help validation of SLP data

• EISCAT can provide overall ionospheric context in which SLP data should be interpreted. Having at the same time Cluster high altitude data would allow more detailed understanding of the phenomena that take place.

• Goal : identify in what situations density enhancement can be expected at 550 km altitude, and when density depletion is created

SLP: scientific objectives cont.

Survey of polar cap arcs

- Monitor density irregularities in polar cap ionosphere and relate those to signatures of polar cap arcs, (e.g. those found in Cluster data).
- Main questions : How often do such features occur? What is their size and motion? What is their relation to the ionospheric conductivity (determined by electron density)?

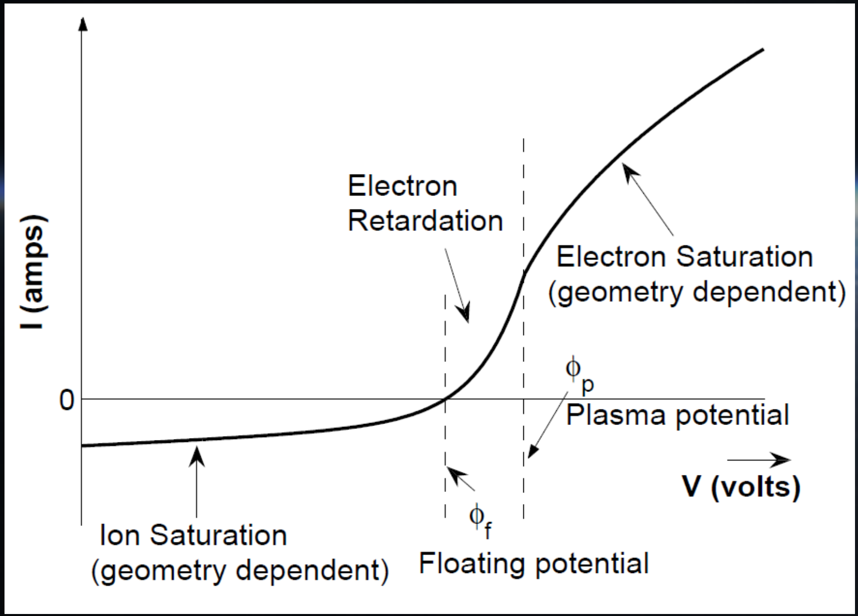
Ionospheric dynamics

- ⇒ coordinated observations with EISCAT’s heating radar
- Heating causes ionospheric expansion and upwelling
- Examine whether SLP does see such signatures
- Study the influence of pulse power and duration on signatures
- Study the effect of relative timing between pulse and PICASSO fly-over

SLP: Measurement principle

Based on conventional Langmuir probe theory

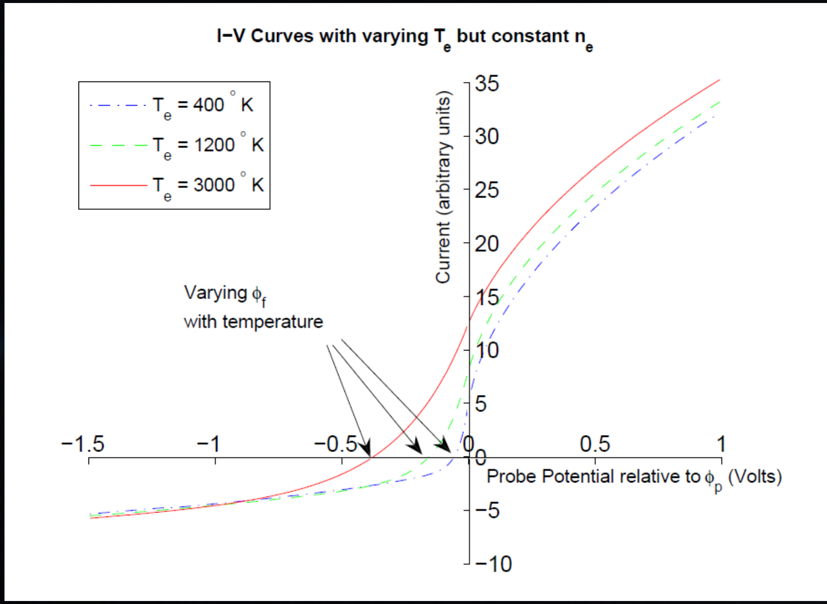
Sweep potential of a probe wrt plasma potential and measure current from probe => current-voltage characteristic
=> electron density and temperature, ion density and S/C potential

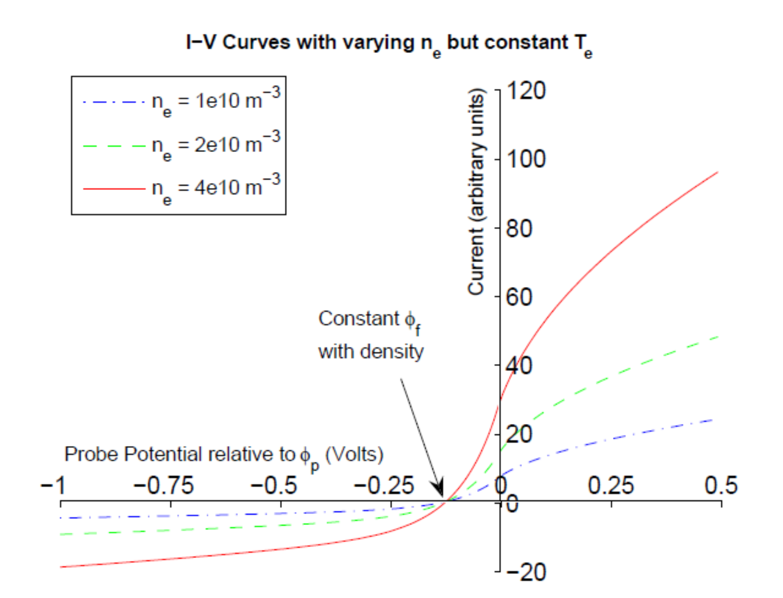


3 regions
- Ni derived from ion saturation region
- Electron T° and S/C potential retrieved from electron retardation region
- Electron density derived from electron saturation region

SLP: Measurement principle

Effect of e- T° and e- density variation on I-V curve



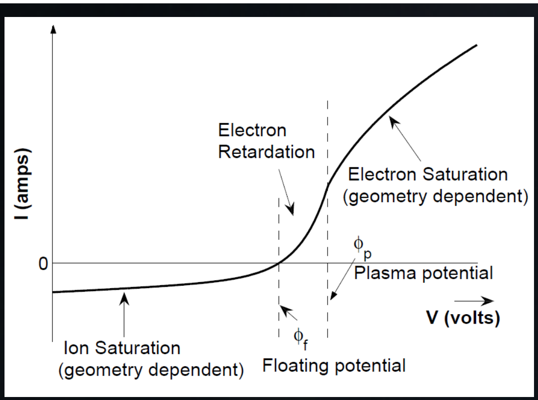


SLP: Measurement modes

Nominal mode

- Sweep: -5 V to +13 V wrt S/C potential
- Sampling freq.: 10 KHz
- Limited downlink bandwidth

  => not possible to perform linear sweeps with very fine steps in nominal mode



- 3 regions measured with different step sizes
- Ion and e- saturation regions: large voltage step size (> 1 V)
- Electron retardation region: smaller step size, which depends on e- T°:

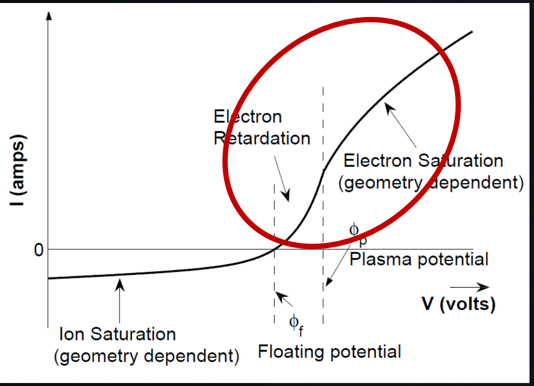
region measured with 30 steps, span is adapted as a function of the temperature
On board, inflection point of the I-V curve (separates e- retardation and e- sat. regions (the plasma potential) determined after each sweep and used to compute the span of the e- retardation region of next sweep.
Step size ranges from ~ 10 mV to 150 mV for e- T° of 600 K and 10.000 K

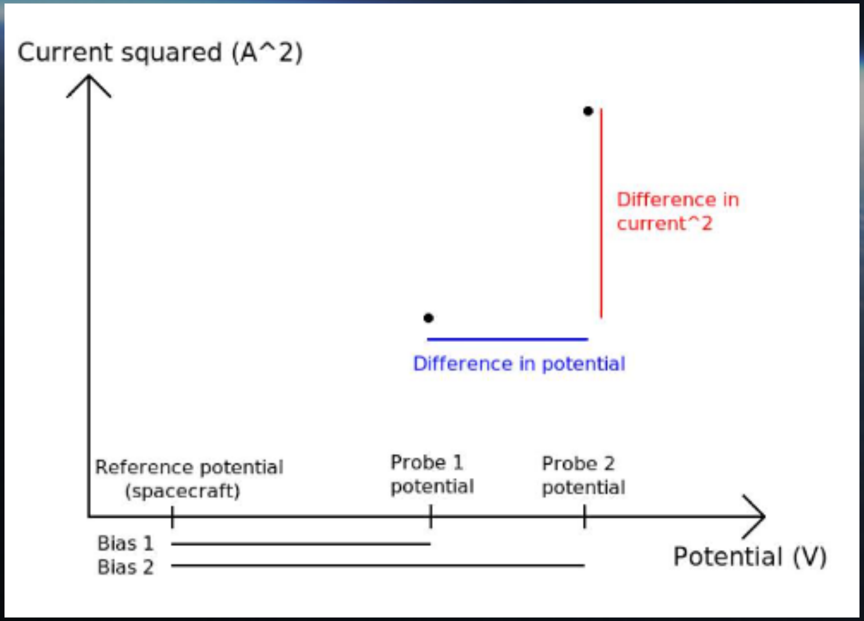
- With 43 samples / sweep => up to 50 sweeps / s
  => ~ 150 m spatial resolution for Ne, Te, Ni and S/C potential)

SLP: Measurement modes

Fast mode

- Based on m-NLP principle
- Constant bias in e- sat. region
- Retrieve only **e- density**
- At least 2 probes simultaneously
- Sampling freq.: 5 KHz
- Spatial resolution ~ 1,5 m
- Can be used to study turbulence
- Huge data volume !!



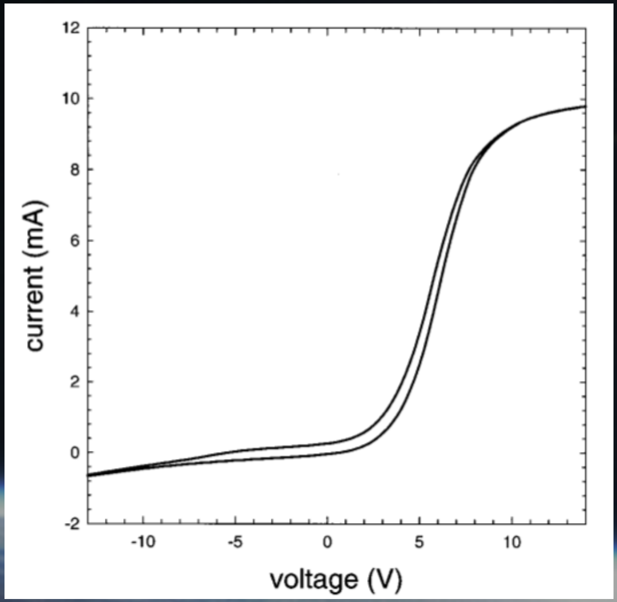


From *T.A., Bekking, University of Oslo*

SLP: Measurement modes

Monitoring mode

- Assess the amount of contamination of probe surface
- Sweep in both directions
- Different sweep durations



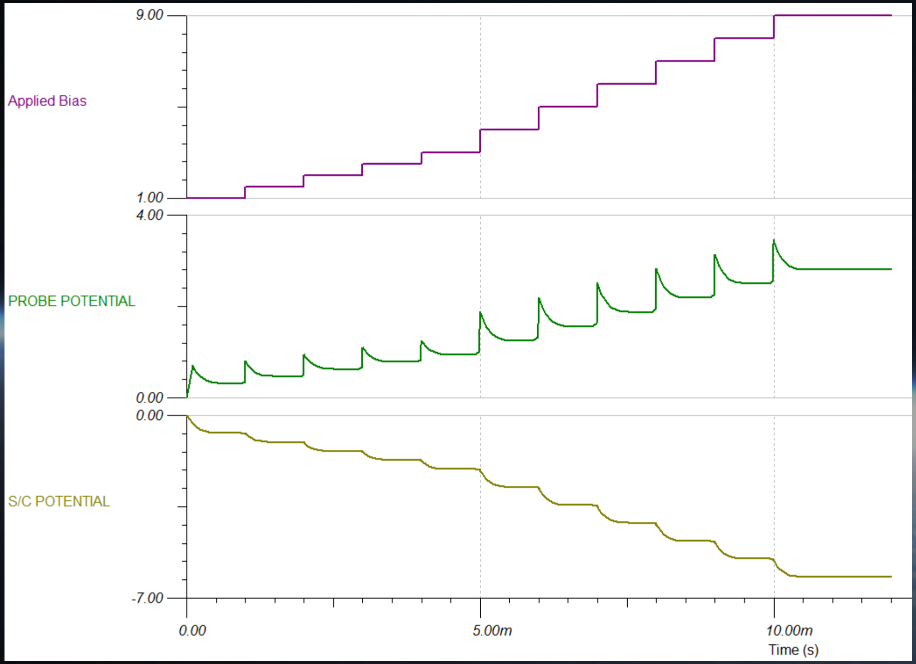
S/C charging

Problem of using LP on board Pico-Satellite:

Limited conducting area of the S/C with respect to the area of the probe

=> Spacecraft charging (e- saturation region)
=>Drift of the instrument's electrical ground during the measurement
=>Unusable data

Risk:
Too low S/C potential: unable to sweep appropriate potentials (e- saturation region)



Solution proposed for other LP on CubeSat: e- gun

Drawback:
- Increased complexity
- Filament quite fragile (high risk for 1 – 2 year mission)

S/C charging

Proposed solution

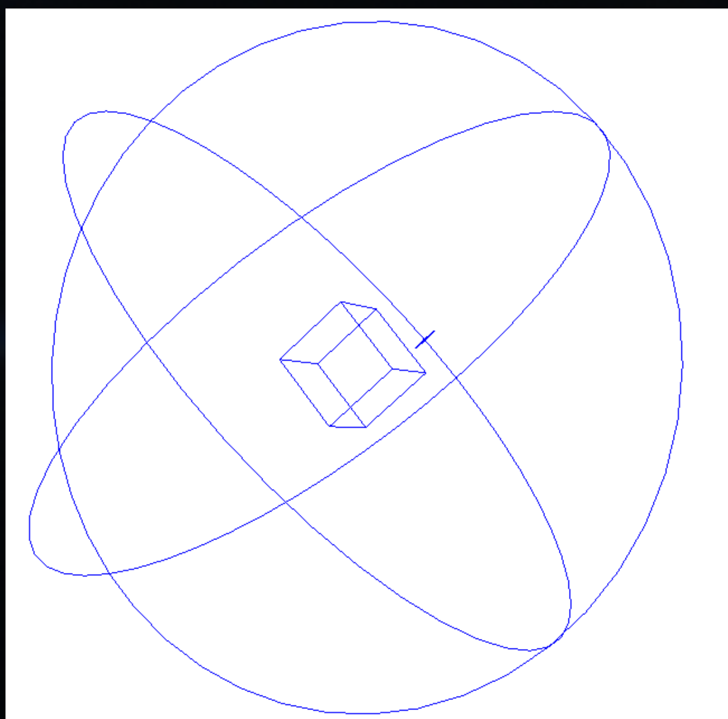
- Increase conducting surface of the S/C (at least 200 cm^2 on all sides of the S/C, incl. solar panels)
- Measure the floating potential of one probe while measuring the I-V curve with another probe
  => The 2 probes that are in the same environment (light/shadow, wake)

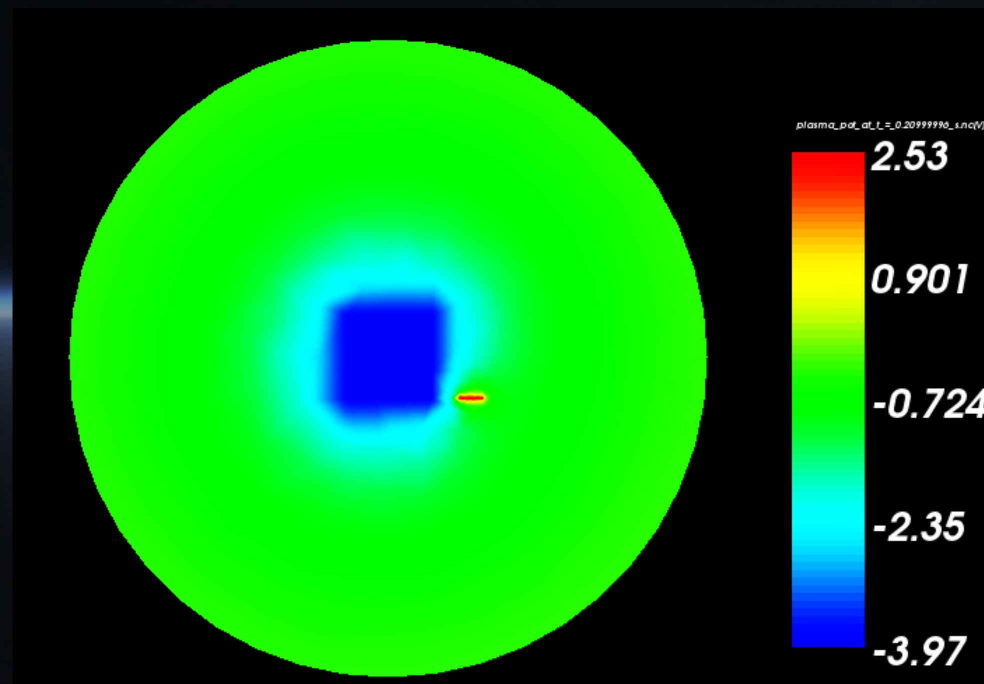
Advantages:
Robust: no filament
No risk of electron collection from e-gun
Gives insight about S/C charging

Disadvantage:
Limited range in e- saturation region in very high density plasma

S/C charging

Particle-in-cell (PIC) modelling and simulations (SPIS)

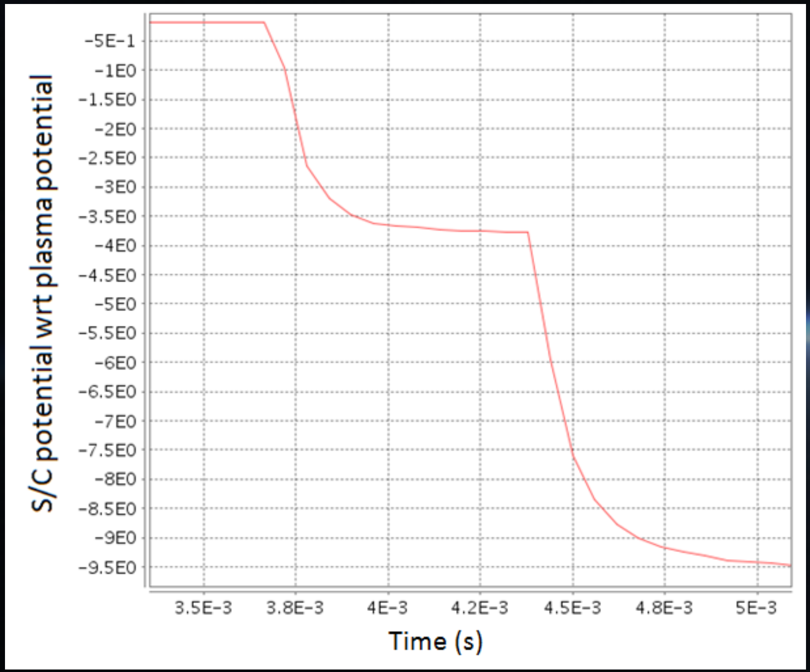




Applied Bias: 6.5 V

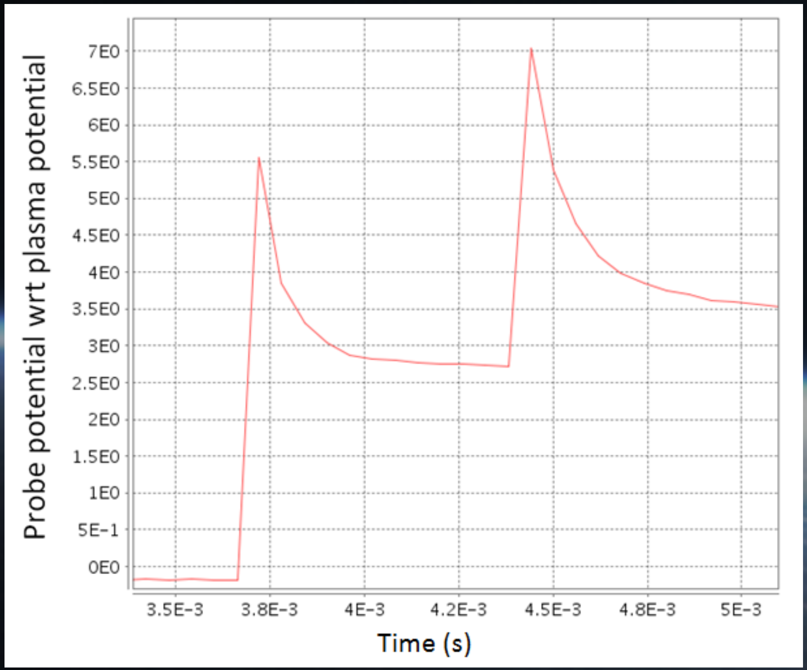
S/C charging

Particle-in-cell (PIC) modelling and simulations (SPIS)



S/C potential wrt plasma potential when 6 V and 13 V steps applied to the probe

Ne = $10^{11}/m^3$, e- T°= 600 K



Probe potential wrt plasma potential when 6 V and 13 V steps applied to the probe

Ne = $10^{11}/m^3$, e- T°= 600 K

S/C charging

Maximum probe potential with respect to plasma potential

SPIS simulations for extreme cases

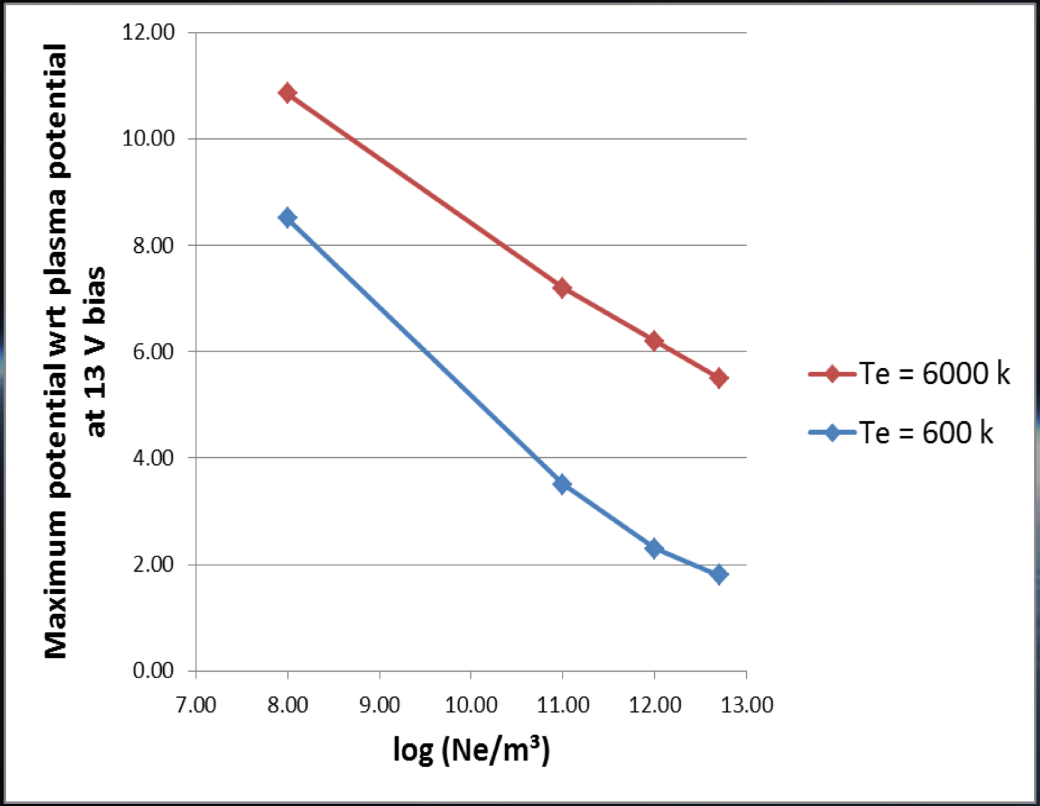
Most unfavourable case:

- High Ne
- Low Te
- Eclipse (no photoelectron)

Floating potential:

-0.16 V for Te = 600 K

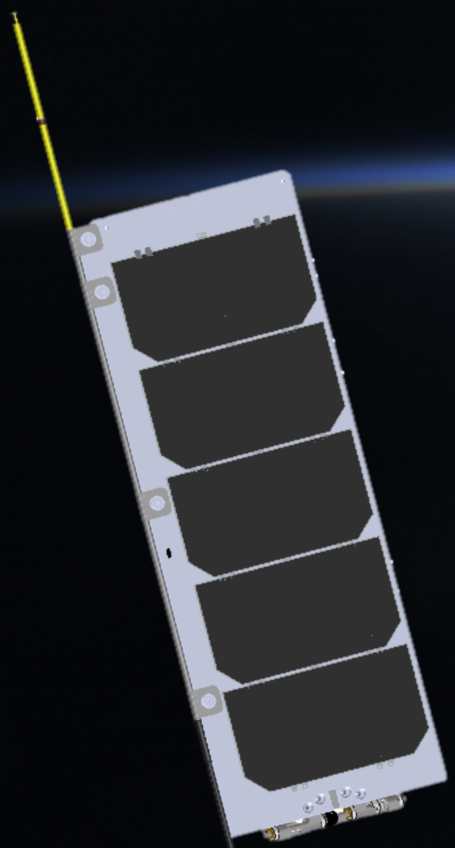
-1.9 V for Te = 6000 K

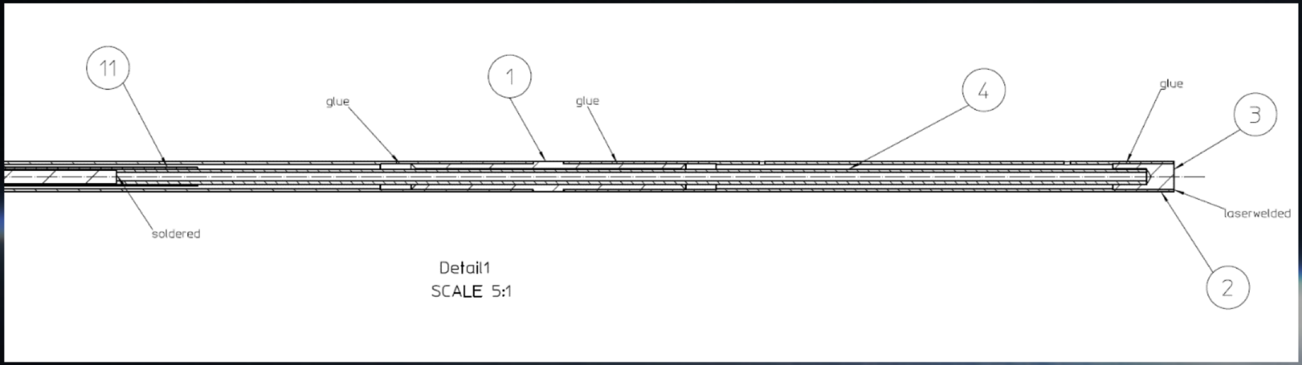


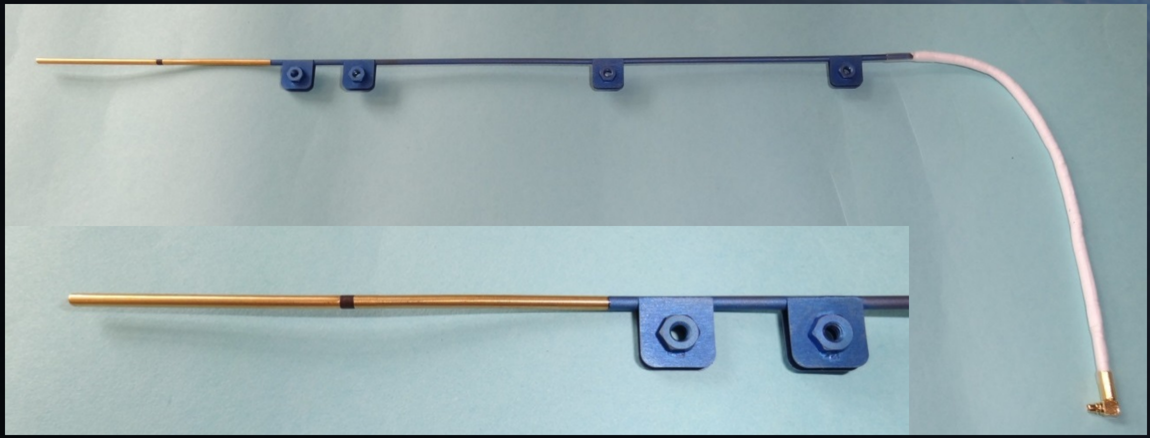
=> Always possible to reach electron saturation region

HW: Probes

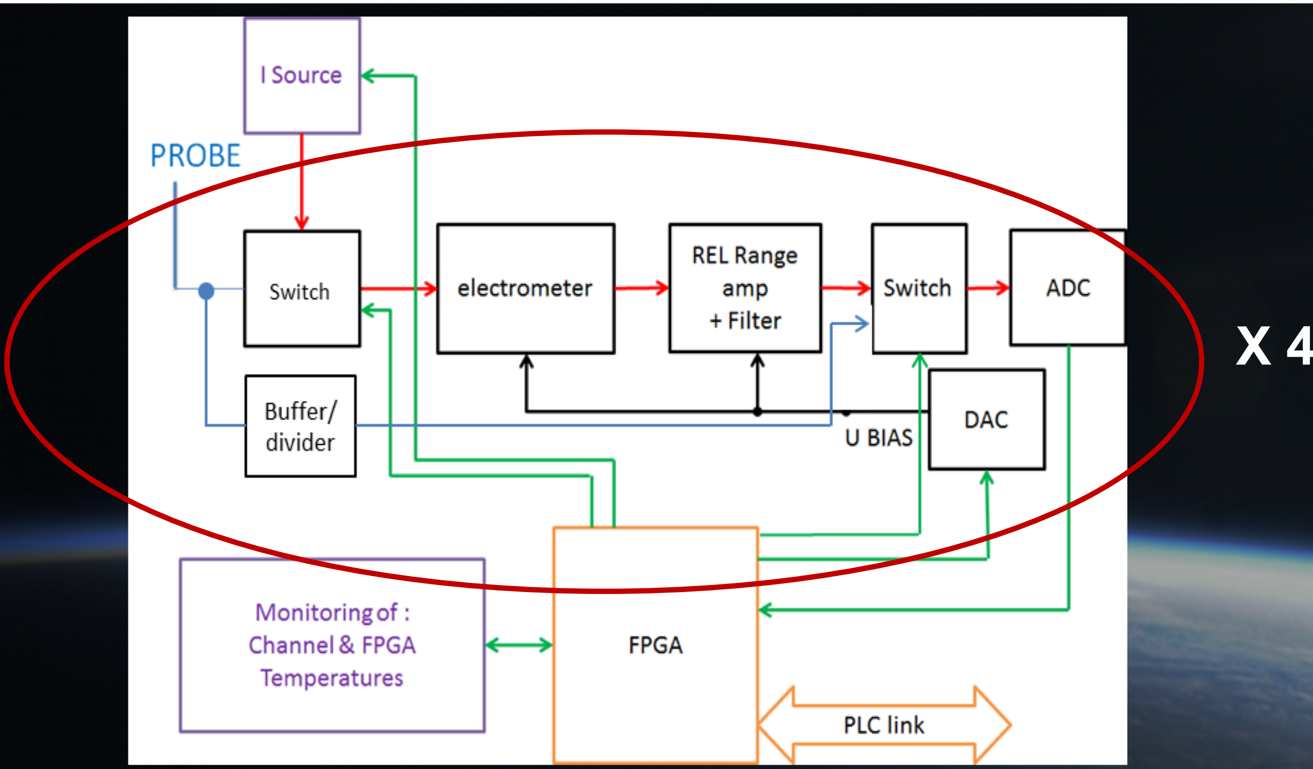
- Probes: 40 mm Ti tubes of 2 mm diameter
- Attached to the extremity of the solar panels via 40 mm boom
- 1 mm diameter Ti tube inside the probe
- Gold plated
- Mass of assembly: 6 g







HW: electronics



- 4 identical channels (either LP or Pot. mode)
- AGC and averaging capabilities, # steps and # samples per step chosen freely
- Automatic adaptation of the span of e- ret. region
- Internal current source for monitoring
- Applied potential (LP mode) can be measured
- Time synchronisation: 1) GPS (NMEA + PPS), 2) PLC

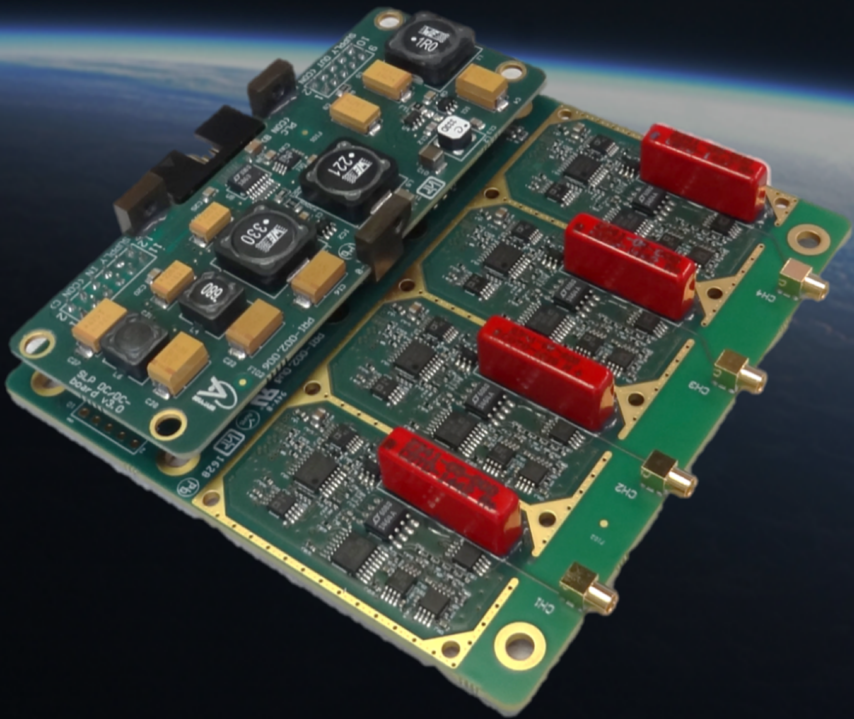
HW: electronics

2 boards:
- PSU
- Main board (FPGA, front end)

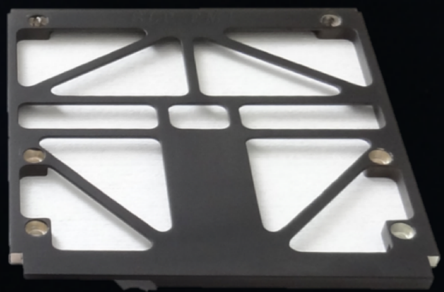
Dimensions:
- 36 x 90.6 x 11 mm (PSU)
- 92 x 95 x 12 (main)
- 104 x 98 x 25 (envelope, incl. shielding cover and mounting bracket)

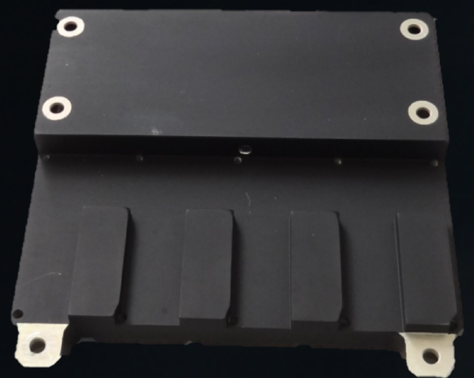
Power consumption (ave.): 2,2 W

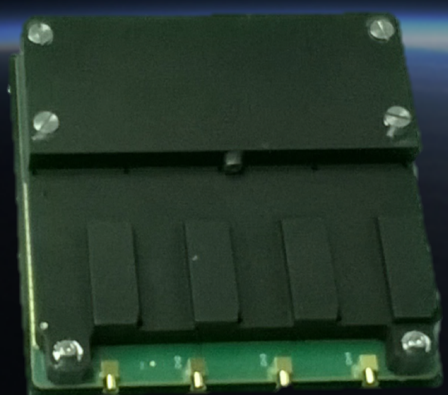
Noise level (std dev.): ~50 pA

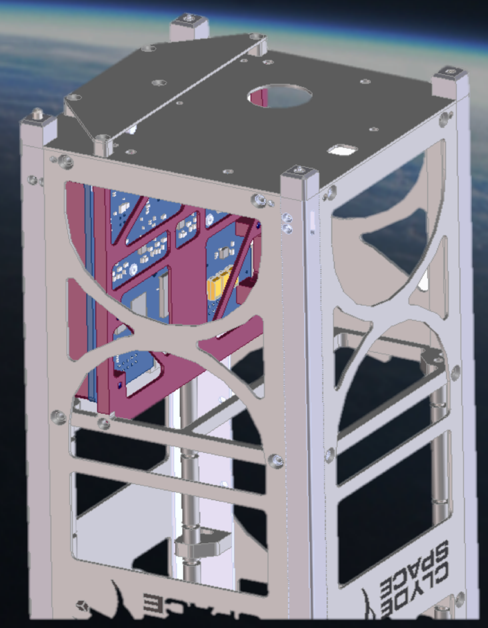


HW: Integration







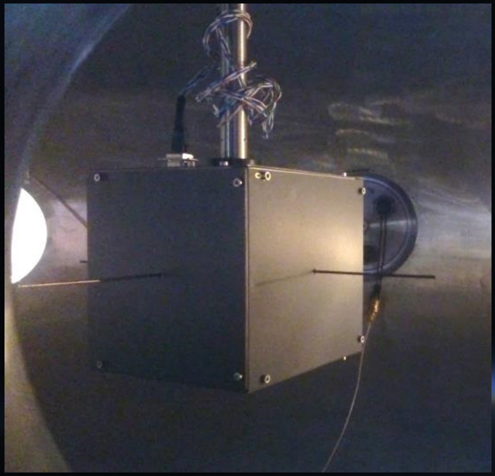


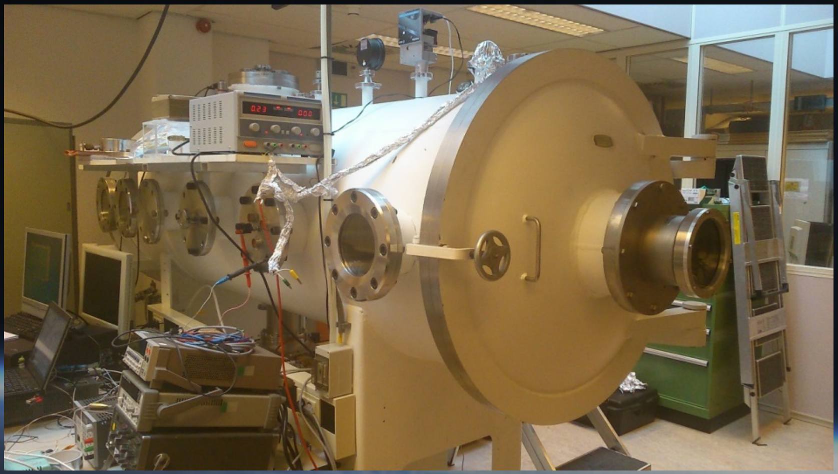
Mass:

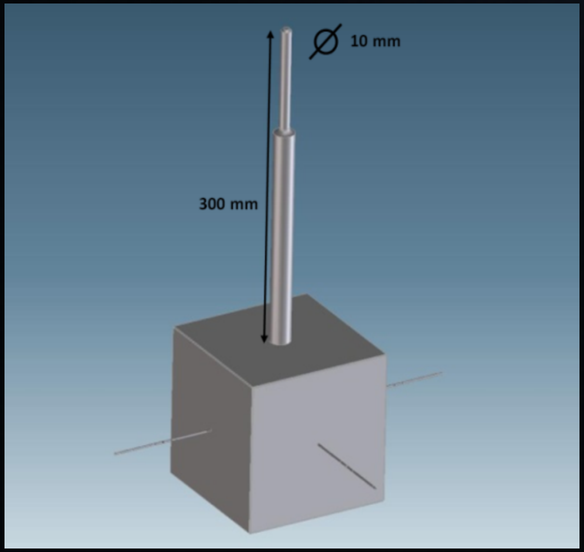
SLP Electronics	87 g
Shielding cover	41 g
4 SLP booms/probes Incl. interface and harness	24 g
TOTAL SLP MASS	152 g

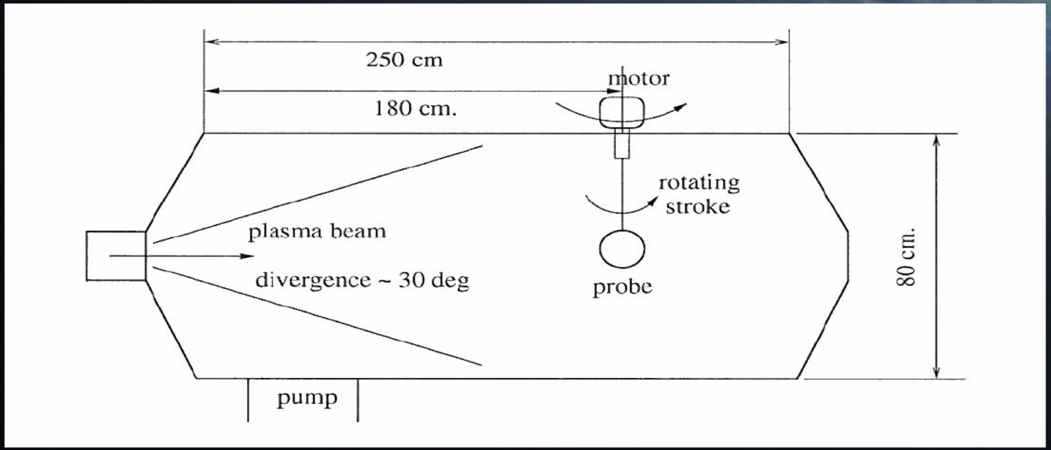
Functional test in plasma chamber

Tests at ESTEC in July 2015, February 2017 and February 2019



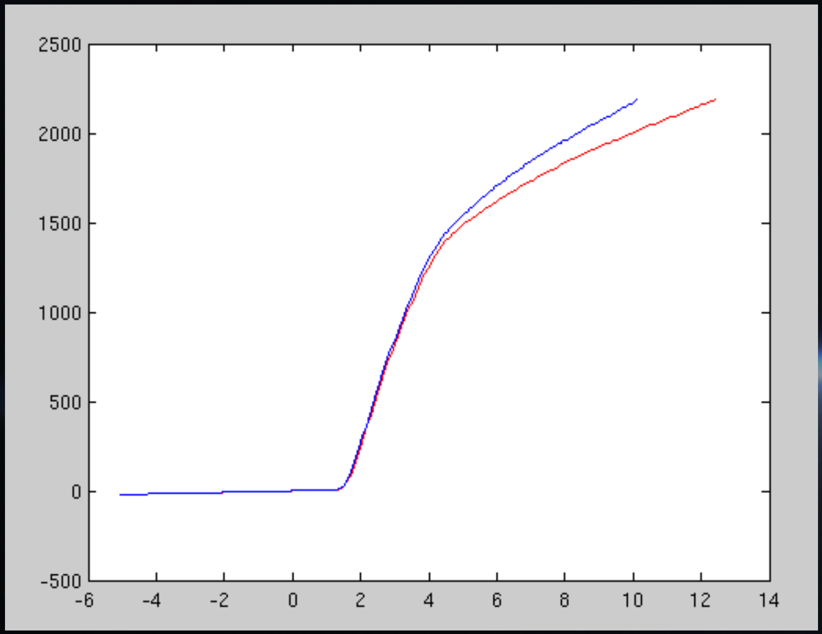




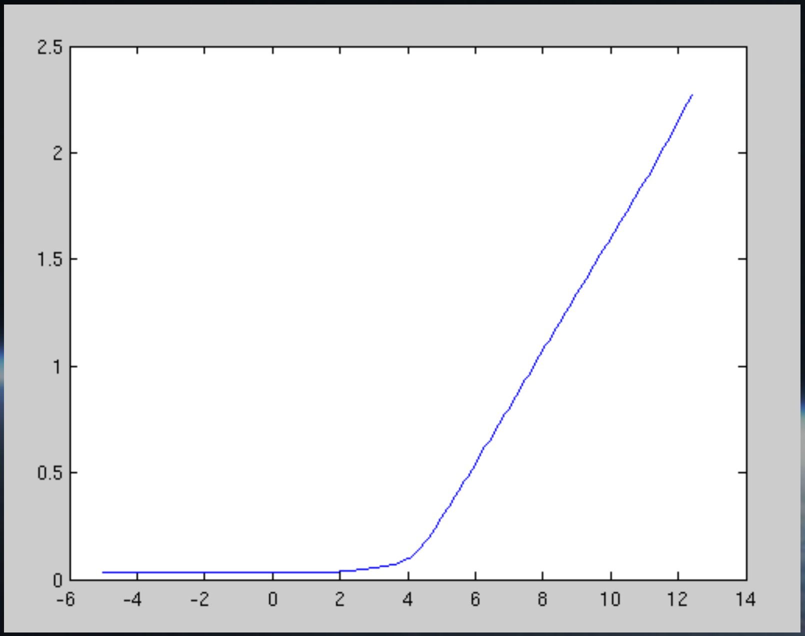


Functional test in plasma chamber

Test of measurement principle



Red: I as function of bias (wrt to S/C GND)
Blue: I as function of bias (wrt to plasma pot.)



Floating pot. As function of applied bias

Thank you for your attention!