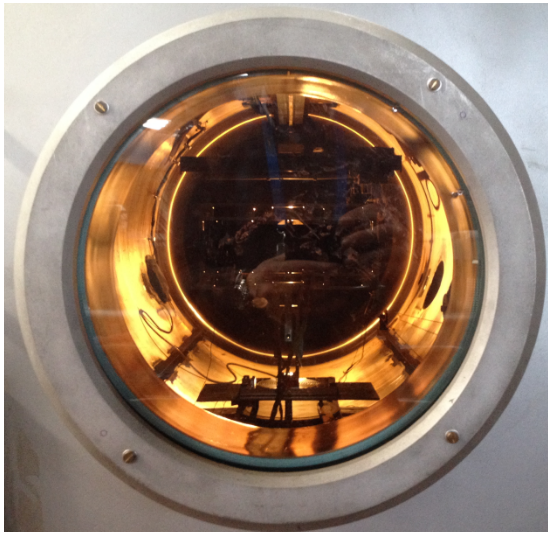
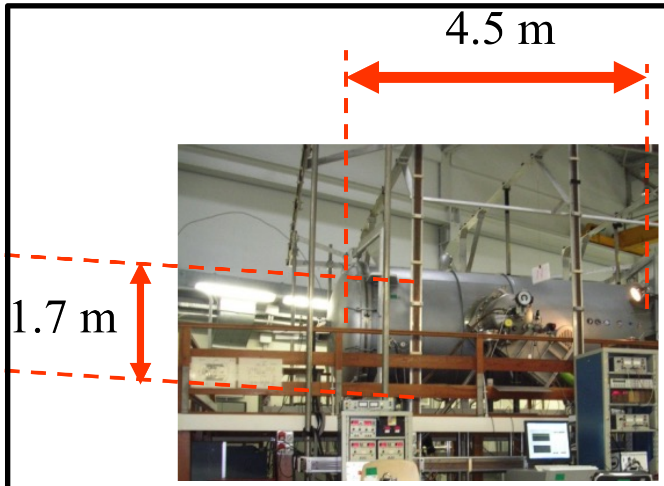
LEE 2022 Meeting

Space Plasma simulator for experimental evaluations of particle-matter interactions



Responsible;	**P. Diego**
Research staff;	I. Bertello, E. De Angelis, E. Papini, A. Parmentier
Electronic support	N. Vertolli
Mechanical / Vacuum system support;	A. Morbidini, F. Tabacchioni

IAPS Plasma Chamber main features



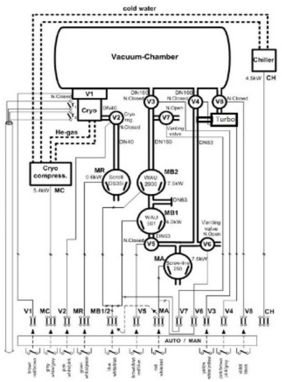
Stainless Steel Cylinder of about 9 m^3

Two large doors (1.7m diameter)

Clean room (ISO 8)

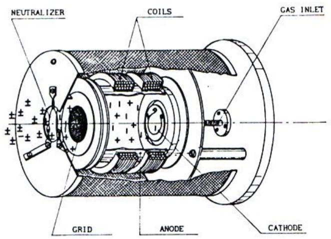
Plasma Chamber main subsystems

Vacuum



5 mechanical pumps
3 turbo-molecular pumps
1 cryo-pump
Limit Vacuum about 3 10^{-7} mbar

Plasma



Neutralized Ar-plasma beam

$Ni \approx Ne \approx 10^{11}\ m^{-3}$

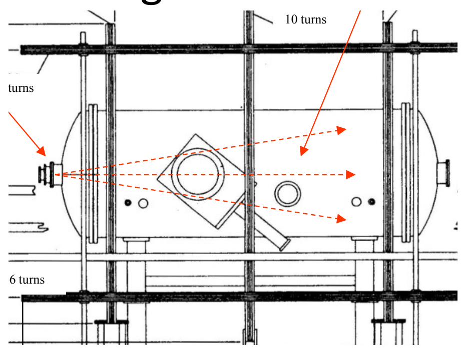
$\lambda D \approx 1$ cm

Neutralized He-plasma beam

$Ni \approx Ne \approx 10^{7}\ m^{-3}$

$\lambda D \approx 1$ m

Magnetic Field



2 magnetic coils system for LEO satellite orbital geomagnetic field simulation

B nullified down to 0,01 G

IAPS Plasma Chamber – Types of Experiments

The plasma chamber developed at INAF/IAPS is a facility capable to reproduce a large volume ionospheric environment, which is particularly suitable to perform studies on a variety of plasma physics subjects that can be summarizes as follows:

- **calibration of plasma diagnostic sensors** (Langmuir probes, Retarding Potential Analyzer,…);

- **characterization and compatibility tests** of components for space applications (materials, coatings, photo-voltaic cells, etc.);

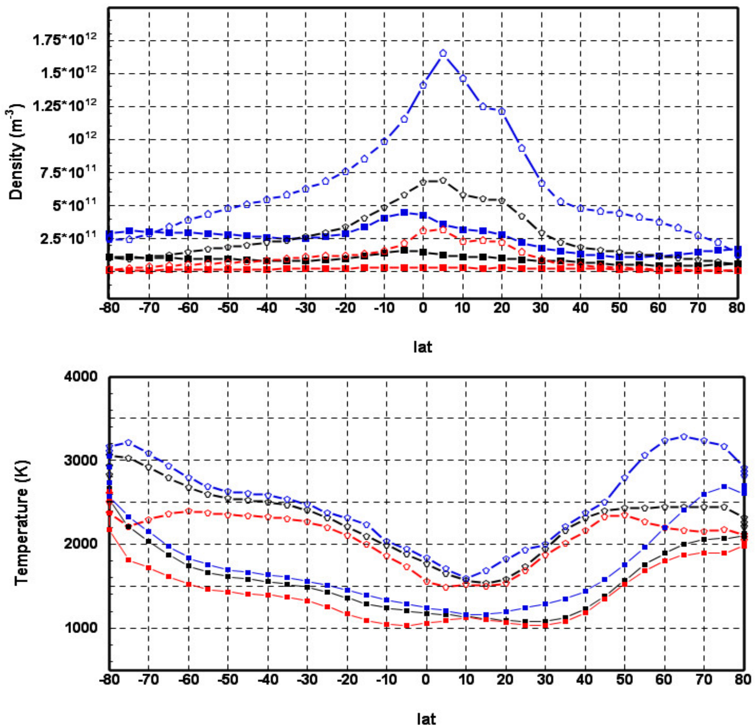
- **functional tests** of experiments envisaged to operate in the ionospheric environment (sensors exposed to space plasma);

- **basic plasma physics experiments** (interaction of charged bodies with plasma, two plasma interaction processes, …);

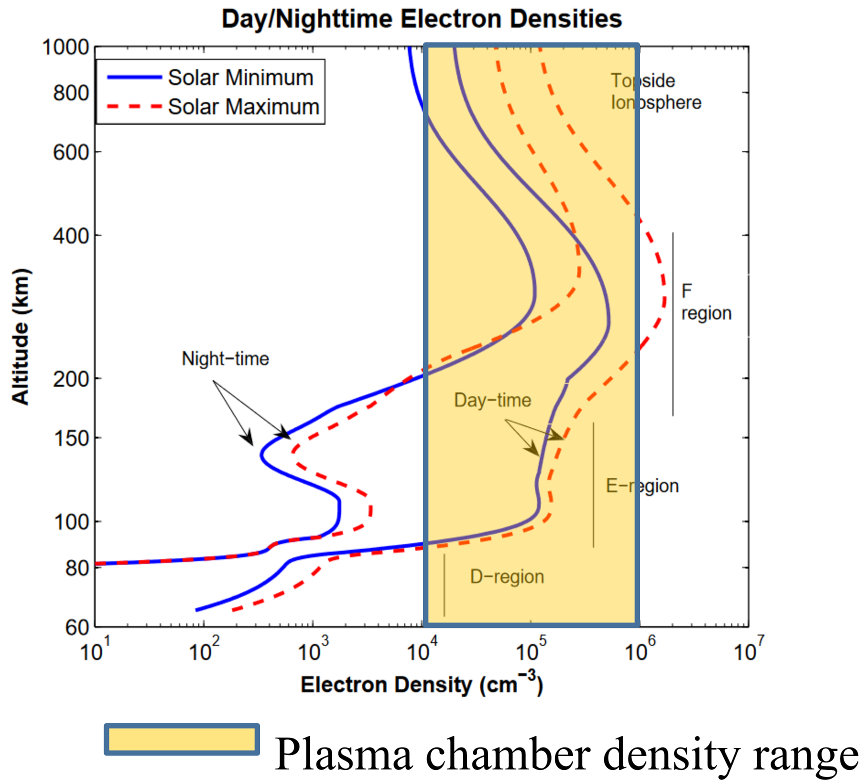
- **tests on active experiments which use cathodes and/or plasma sources** (ion thruster, ion beam neutralizers, ….).

Experimental target - Low Earth Orbit environment

Latitudinal and solar cycle variability of plasma parameters are fully covered by experimental simulator



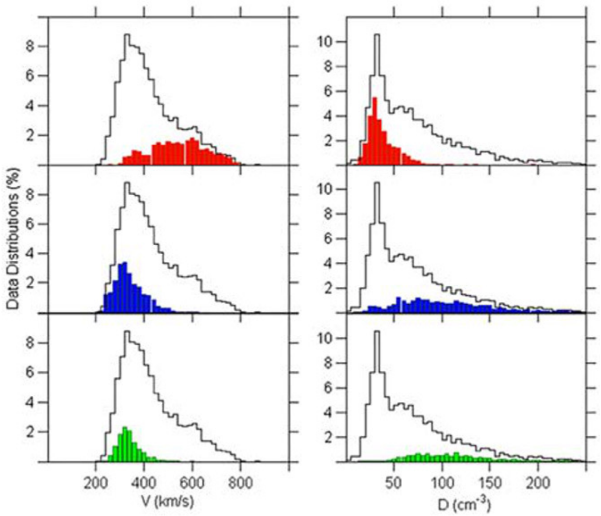
Data from IRI model Virtual Ionosphere, Thermosphere, Mesosphere Observatory" (VITMO) using International Reference Ionosphere model; Sun-synchronous orbit, 500 km altitude

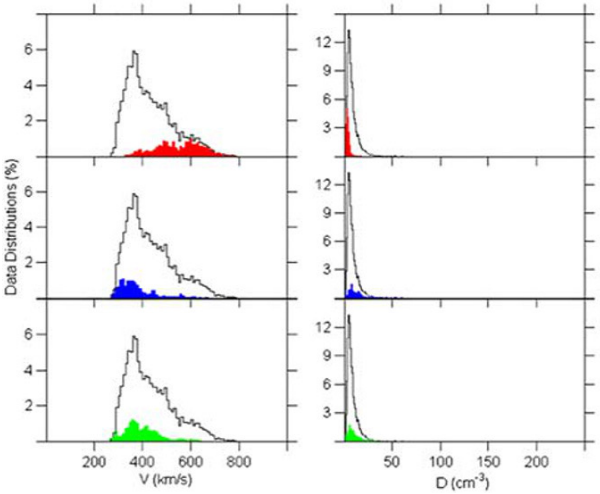


Good coverage of altitude variability profile of plasma density

Solar forcing, latitudinal and LT induced variability strongly alter plasma parameter (e.g. plasma density depletions)

Experimental target - Interplanetary space environment



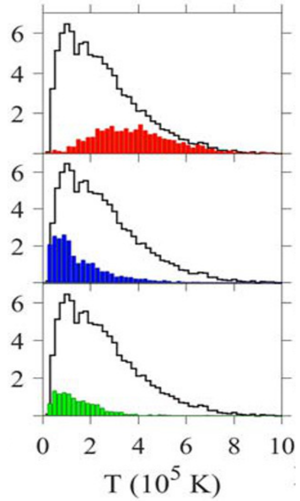


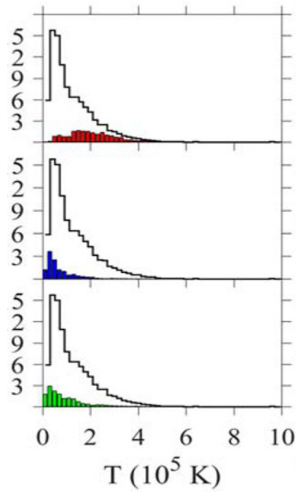
Solar wind parameters are modulated by coronal activity

Interplanetary space perturbation are characterized by different levels of velocity, density and temperature.

Space Weather studies the relationship among various solar inputs and the planetary environment responses

Space plasma physics needs accurate monitoring of variations in a large range rather than precise measurements (broad range – low resolution)





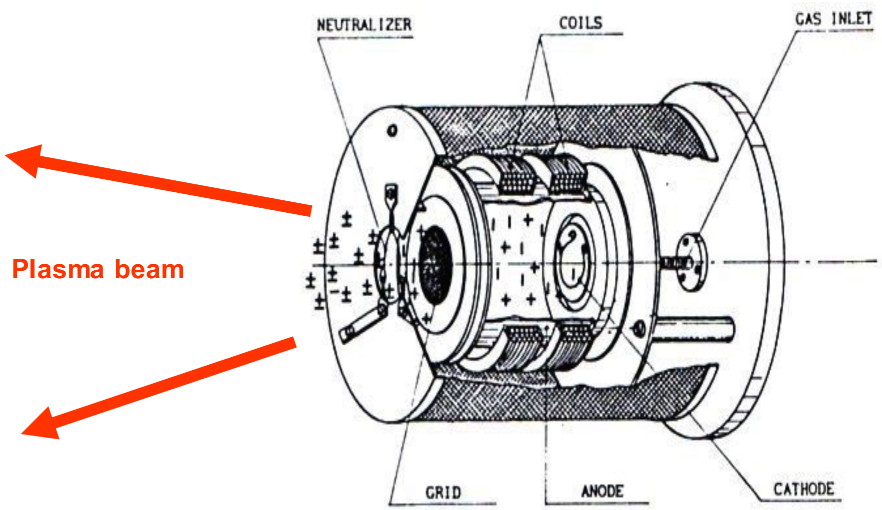
SW velocity, density, and temperature. Helios data recorded at Mercury's orbit. White shape represents the entire data set, while colored ones represent HSSs (red), MCs (green), and NCDEs (blue).
Lower panels show the same parameters recorded at 1 AU.

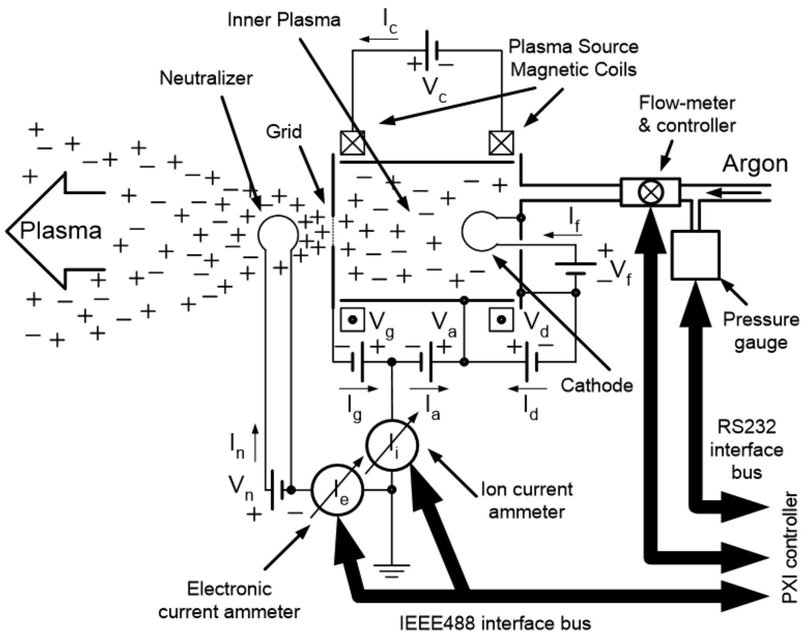
Diego et al. 2020 - 10.1029/2020JA028281

The plasma source - Low Earth Orbit environment

The plasma source is derived by an ion thruster (Kaufman). This source produces an **Argon** plasma with parameters (i.e. electron density and temperature) very close to the values encountered in the daytime ionosphere at F layer altitudes.

The plasma generated by the source is accelerated into the chamber at a velocity that can be tuned to simulate the relative motion between an object orbiting in space and the ionosphere (≅ **8 km/s**). This feature, in particular, allows laboratory simulations of compression and depletion phenomena typical of the **ram** and **wake** regions around ionospheric satellites (e.g. ISS).



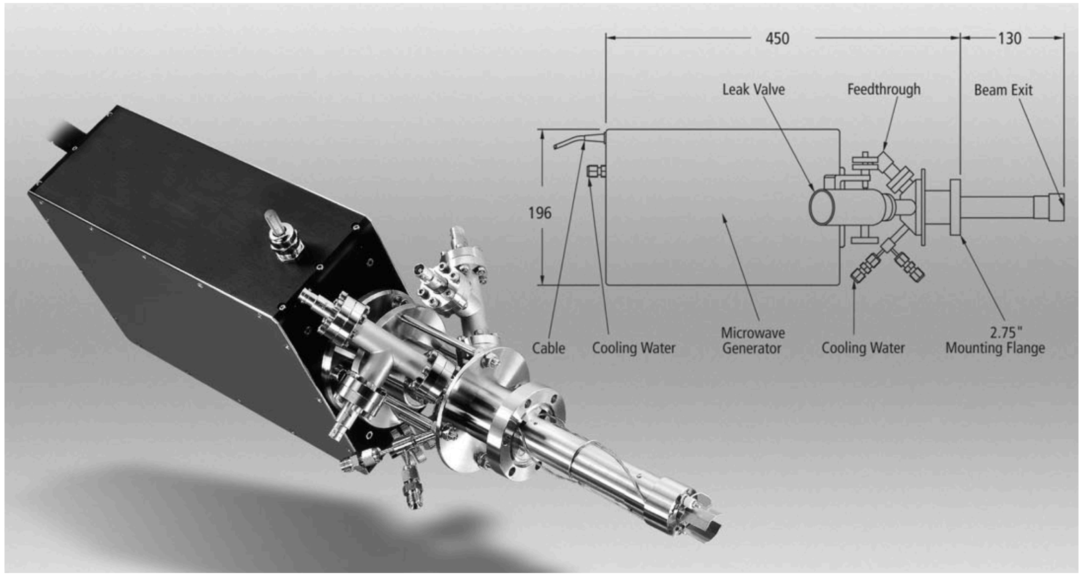


The plasma source - Interplanetary space environment

The Solar Wind (SW) plasma generator is derived by a SPECS MPS-ECR ion source.

Helium ions beam is reduced by a pin-hole to obtain the SW density (∼**10^7 m^{-3}**) and hot electrons are suppressed by a polarized grid.

The plasma is accelerated into the chamber at a velocity of the inner heliosphere SW (∼**330 km/s**).

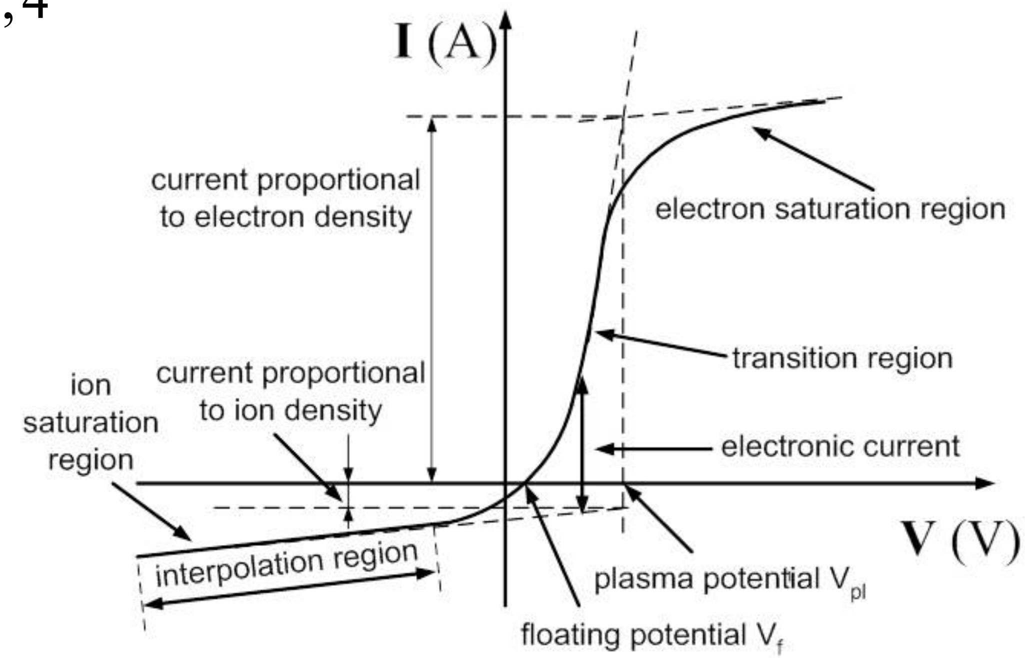


Ion beam is neutralized outside the source to obtain a plasma with Debye lenght ∼ 1 m

Conductive body in space plasma

A conductive body in plasma collects ions and electrons until it reaches the **floating potential Vf** to attain the equilibrium among currents

$$\sum_k I_k = 0 \qquad k = 1,\dots,4$$



Total current is the sum of:
- Ion current
- Electron current
- Photo-electron current
- Bias current

Due to different mass and thermal velocity:
- electrons flux is almost isotropic
- ions flux is directional

The floating potential is negative wrt plasma potential

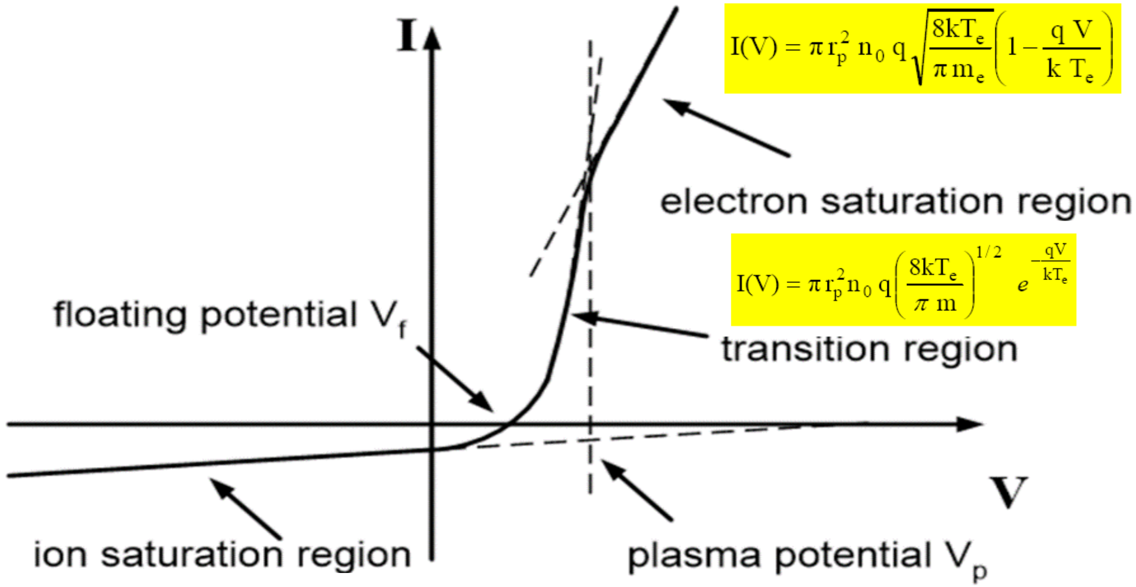
$$V_p - V_f \approx 5\ kT_e/q$$

Plasma Diagnostic

The plasma parameters can be retrieved by applying a voltage ramp to a conductive sensor thus obtaining the characteristic curve I-V

I-V curve has three branches:

- Ion saturation
- Transition exponential region
- Electron saturation region



$$I(V) = \pi r_p^2 n_0 q \sqrt{\frac{8kT_e}{\pi m_e}}\left(1-\frac{qV}{kT_e}\right)$$

$$I(V) = \pi r_p^2 n_0 q \left(\frac{8kT_e}{\pi m}\right)^{1/2} e^{-\frac{qV}{kT_e}}$$

Analytical model for the various currents is needed

$$I = \pi p_g^2 q v_{ion} n_i = \pi r_p^2 q v_{ion} n_i \left(1-\frac{2qV}{m_i v_{ion}^2}\right)$$

Orbit Motion Limit (OML) theory is the most used to model the I-V curve to easily retrieve plasma density and temperature

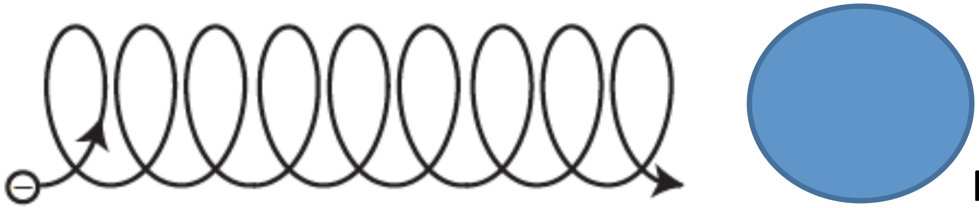
The hypothesis are:

- thick sheath (**probe radius** $\leq$ **plasma sheath** $\sim$ **several Debye length**),
- Maxwellian electrons
- Electrons flux isotropic (B and E fields negligible)

LEE sensitivity to enviromental conditions – Magnetic field

OML equations do not include magnetic field effects
Electron flux is considered isotropic

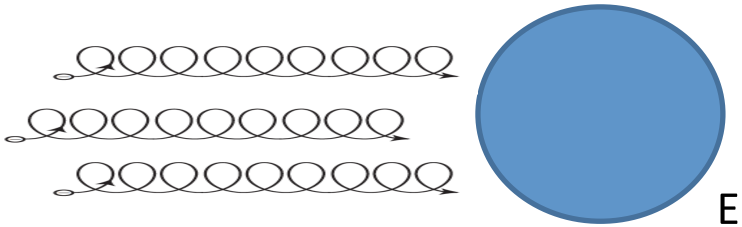
Magnetic field effect depends on the Larmor radius (RL) and probe radius



RL ≈ Probe radius

⇩

Magnetic field effect is negligible



RL ≪ Probe radius

⇩

Electron density is underestimated

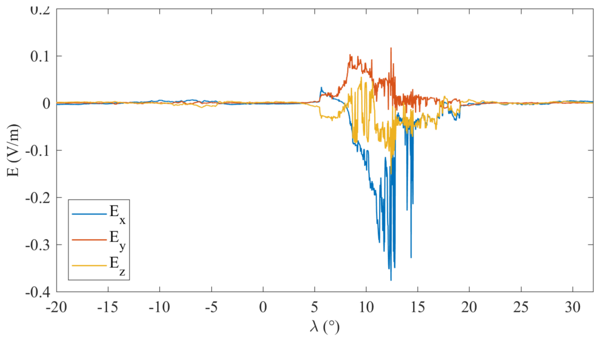
Geomagnetic field induces RL grater than about 2 cm

Thus it is sufficient to design probes not greater than RL to avoid OML failure and density underestimation

LEE sensitivity to enviromental conditions – Electric field

Also Electric fields (E) are not considered in OML theory.
Several tens of mV/m are capable to alter the electrons collection on the probe surface.

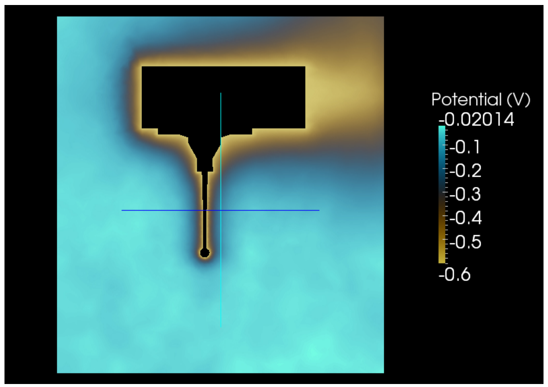
Strong E field can be encountered either at low latitude (plasma bubble) or at high latitude (auroral oval).



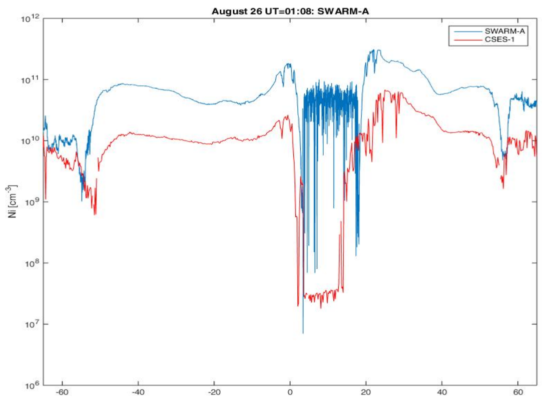
Diego et al. 2021

S/C potential can induce very strong E field on the sensors in case of short distance wrt plasma sheath dimensions

Sheath dimension increases for decreasing density



Chiaretta M., Report 2011

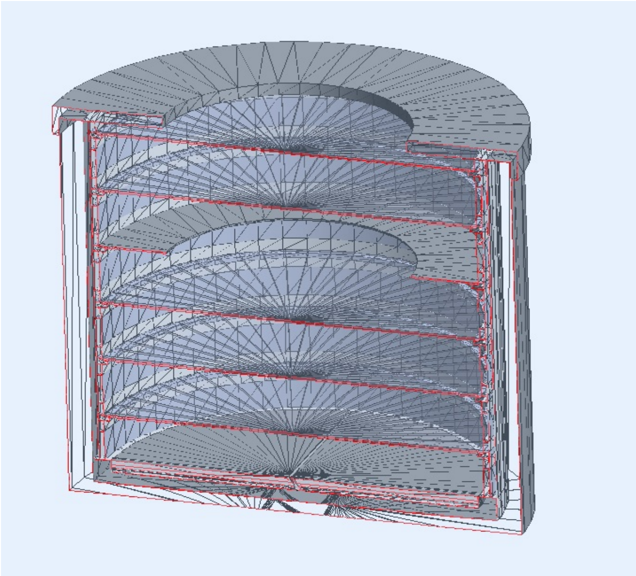


In case of S/C induced E field, the probe saturation does not allow the correct measurement.

Plasma Diagnostic – electrons issues

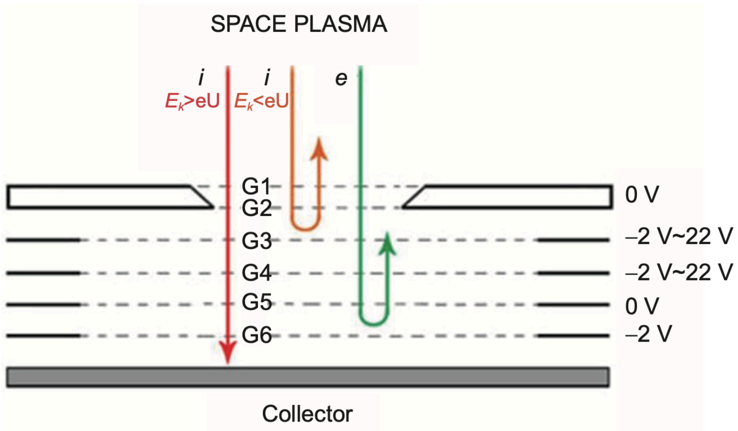
Other plasma parameters to be monitored:

- ion energy
- ion drift
- ion species



Instruments are designed as polarized cavity (e.g. RPA, IDM, ICM) to avoid electron entrance.

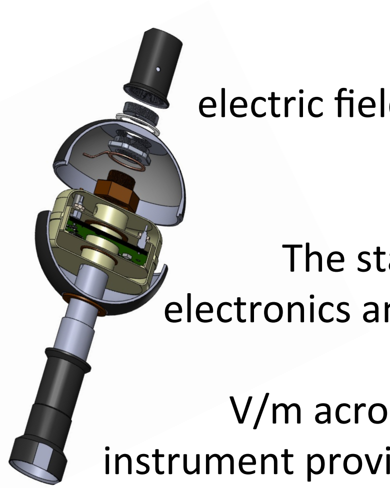
Plasma electrons alter the corrent collected by the electrode



External grids should be at GND (or slightly negative) to stop the low energy electrons

Inner grids are negative polarised to suppress the secondary electrons emission

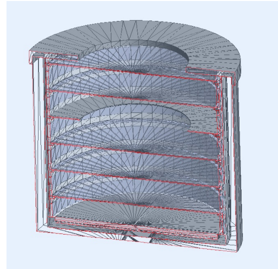
Instruments for space plasma monitoring



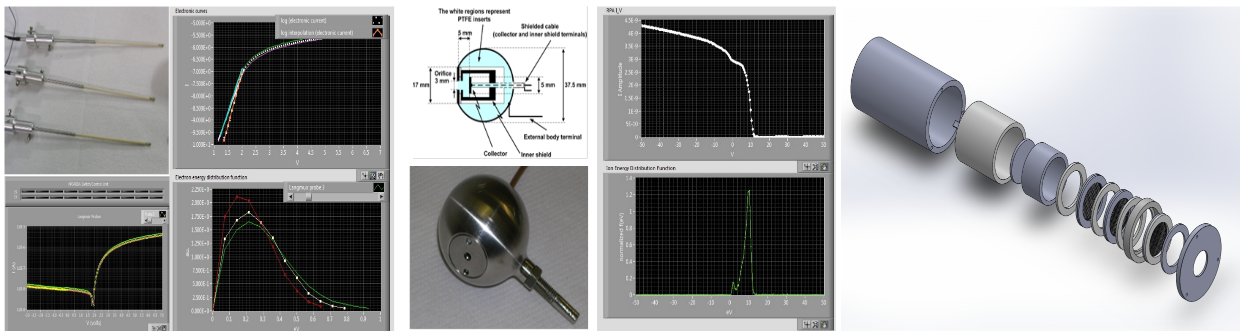
Electric Field Detector EFD
designed to measure the ionospheric electric field components as a voltage difference between multiple probe pairs.

The state-of-the-art design of the front-end electronics and analog acquisition board enables a sensitivity in the order of
V/m across the range from DC to 3.5 MHz. The instrument provides sensor potential in the ULF band, electric field components in the ELF and VLF bands, and FFT in the HF band.

Plasma Analyzer
Innovative concept fit for cubesat constraints.
The segmented electrode allows for detection of plasma velocity direction as an Ion Drift Meter.



The polarization of the external grids prevents electrons from entering the sensor cavity, while inner grids allow the measurement of energy and variation for different ion species.



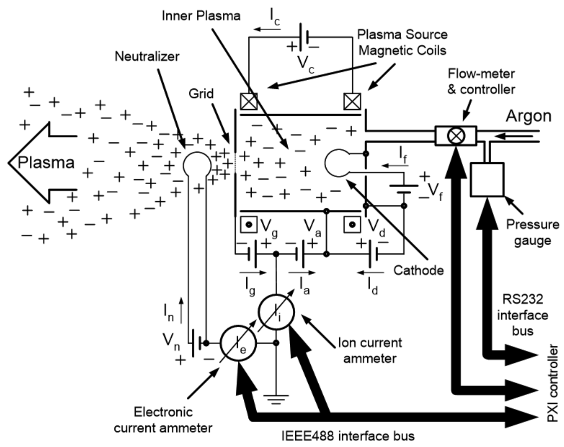
Langmuir probes to measure plasma density and temperature (left figs.), **RPA** to measure ionospheric plasma energy (central figs.), and solar wind energy (right fig.)

Plasma Diagnostic for Laboratories
Sensors and acquisition systems are being developed by the team to monitor plasma parameters inside the SWIPS chamber at INAF/IAPS.
This monitoring is needed to characterize other instruments, prototypes, and various kinds of space borne technologies.

Conclusion and final remarks

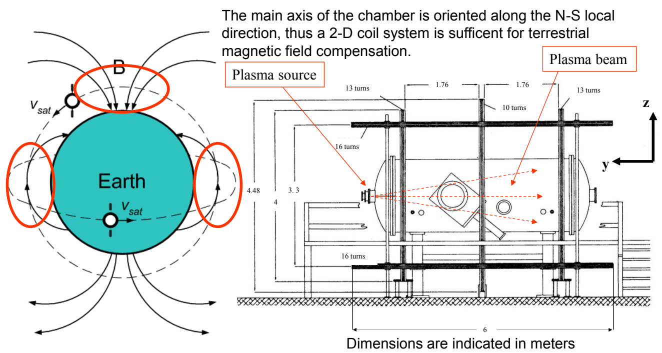
Possible experimental activities of **LEE working groups can be supported**

- Plasma Chamber of INAF-IAPS is able to reproduce the space environment



- The most peculiar feature of the facility is the **Low Energy electrons** of the plasma

- It is possible to perform experiments with **induced (or nullified) E and B fields**



- Plasma diagnostic system should be considered as essential part of a space borne experiment

Thank you