

Máster Universitario en Ingeniería Aeronáutica

# The Space Environment

Plasma diagnostic with Langmuir probes

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POLITÉCNICA

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Based on the work by Luis Conde

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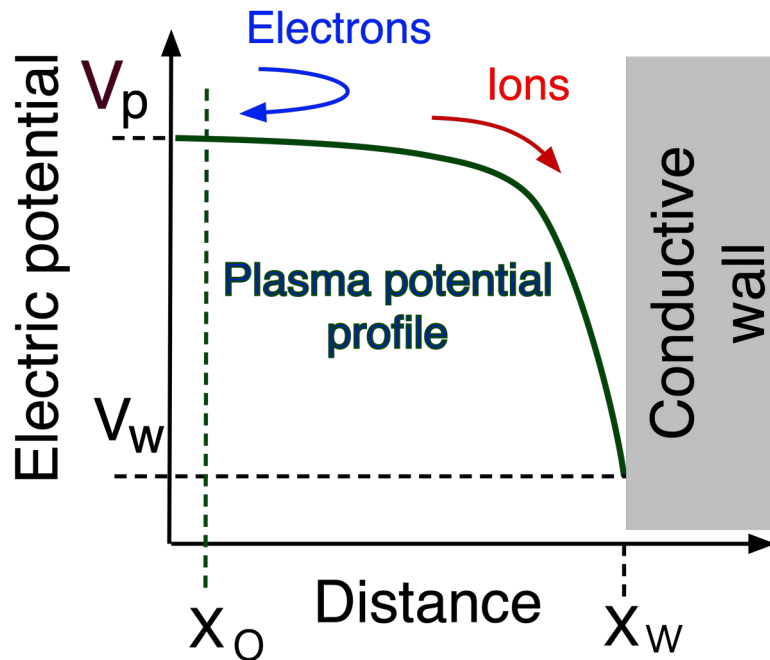
Departamento de Física Aplicada

# Ion collection by metallic surfaces

- Metallic surfaces interact with the ambient plasma through an electric potential profile called *plasma sheath*. For the evaluation of the ion current to a conductive surface we consider in the steady state a one-dimension model under the following assumptions,

- The distant plasma  $x < x_0$  is quasineutral  $n_{e0} \approx n_{i0} = n_0$  and  $V_p$  is uniform in space.
- The electric potential  $V_p > V(x) > V_w$  with respect to the ambient plasma is negative.
- The ions are attracted and Maxwellian electrons are repelled by the wall.

The flow of ions is  $\Gamma_i = n_i(x) u_i(x)$  and continuity equation and energy conservation gives,



$$\left. \begin{aligned} \Gamma_i &= n_{i0} u_{i0} = n_i(x) u_i(x) \\ \frac{m_i}{2} u_i^2(x) + e V(x) &= \frac{m_i}{2} u_{i0}^2 + e V_p \end{aligned} \right\} \begin{aligned} \varphi(x) &= V(x) - V_p < 0 \\ n_i(x) &= \frac{n_{i0} u_{i0}}{\sqrt{u_{i0}^2 - \frac{2e}{m_i} \varphi(x)}} \end{aligned}$$

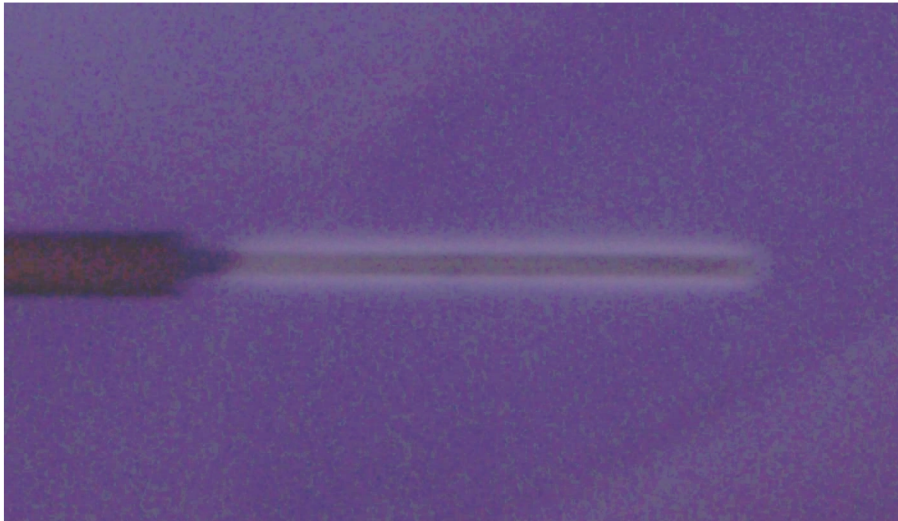
The electrons have a Maxwellian distribution and  $n_e(x)$  decreases along the plasma potential profile as  $V(x) > V_w$  becomes more negative,

$$n_e(V) = n_{e0} \exp\left(\frac{e(V - V_p)}{k_B T_e}\right) \quad \text{equivalently,} \quad n_e(\varphi) = n_{e0} \exp\left(\frac{e \varphi}{k_B T_e}\right)$$

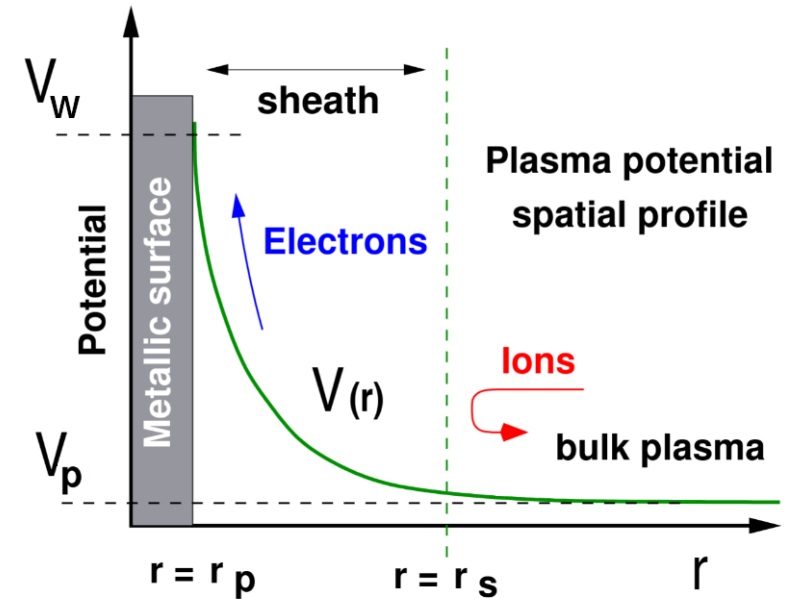
The heavy ions move driven by the electric field whereas the more mobile electrons are distributed by the electric potential profile.

# Positive potential respect to ambient plasma

- Surface is biased positively with respect to plasma  $V_w \gg V_p$
- Electrons are attracted to the surface while ions are repelled back to the bulk plasma
  - Not all ions are repelled due to their larger mass (higher potential is required for this)
- Electrons might gain extra energy and interact with the neutrals (excitation and emission of light)



Electric probe biased positive accelerates electrons and these interact with the neutrals (Ar), emitting light.



# Floating surface

- A metallic surface in contact with a plasma that is **not** polarized to a potential will be *floating*
- This means that the ion and electron current balance so the total charge reaching the surface is 0
- The surface reaches a potential that is called the *floating potential*
- **WARNING:** This does **not** mean that the plasma and the surface are at the same potential!
  - The floating potential is typically lower than the plasma potential
- This is the situation of an *unconnected* probe.

$$I = I_e + I_i = 0$$

$$\phi_w \simeq \frac{1}{2} \ln \left( \frac{m_i}{2m_e} \right)$$

# The I-V curve

- $V_p$ : Probe polarization potential
- $V_{sp}$ : Plasma potential.
- $V_F$ : Floating potential. Ion and electron current are equal

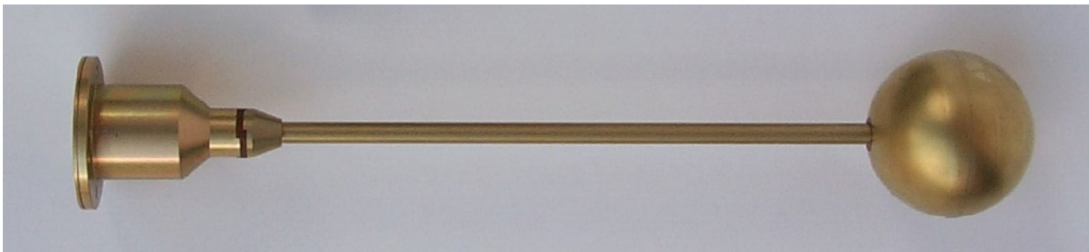
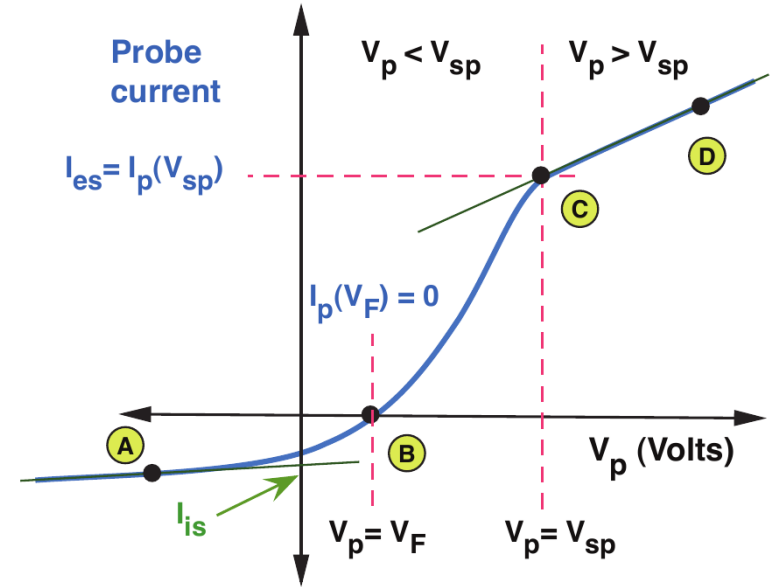
A typical I-V curve has different regions

A) Ion saturation current.  $V_p \ll V_{sp}$ . All relectrons are repelled and only ions are captured.

B) Floating potential. Net current going through the probe is zero,  $I_e = I_i$

C) Plasma potential equals probe bias. All electrons in the plasma are collected

D) Electron saturation current. Current increases due to increase of sheath size. Depends on probe geometry.



One of the two Langmuir probes on board Roseta.

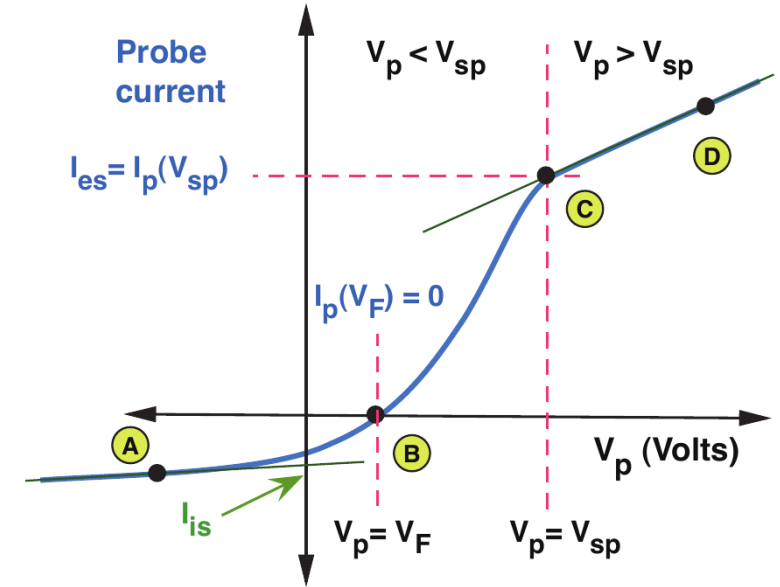
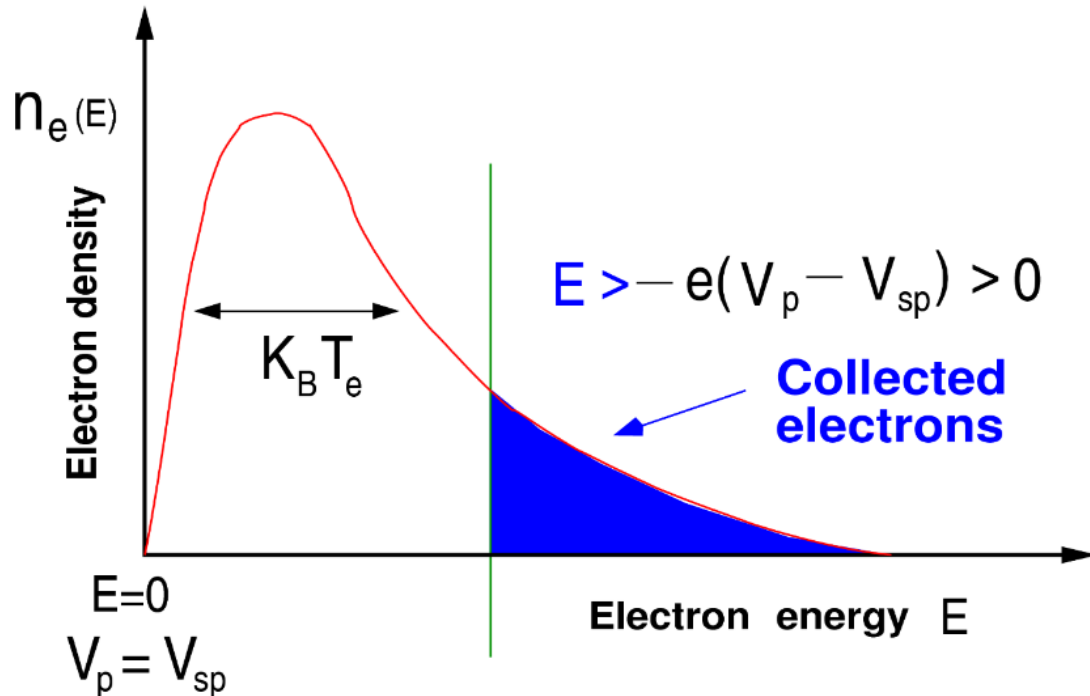
# The I-V curve: B-C

In this region, the collection of electrons transist from collecting all (C) to a point in which most of them are rejected (B) as  $I_i \ll I_e$

It is usually denominated the *electron retarded field*

Only electrons with energy  $> -e(V_p - V_{sp})$  are collected.

The lower  $V_p$  with respect to the plasma potential, fewer electrons are collected.



# The I-V curve: Temperature estimation

If we assume a Maxwellian plasma, the current between BC and the saturation current are related with an exponential law.

$$I_{BC} = I_s \exp\left(\frac{e(V_p - V_{sp})}{K_B T_e}\right)$$

$$v_{th} = \left(\frac{8K_B T_e}{\pi m_e}\right)^{(1/2)} \quad I_{es} = \frac{1}{4} S n_e v_{th} \quad \begin{cases} S = 4\pi r_p^2 \\ S = 2\pi r_p L \end{cases}$$

I-V curves are typically plotted in semi-analytical plots.

Electron density can be extracted from the saturation current, if temperature is known

Temperature is then the inverse of the slope (after subtracting the ion current).

Generally, we can relate the second derivative of the current respect to the voltage to the energy distribution function.

$$\frac{d^2 I}{dV_p^2} = -(e^2 \pi r_p^2) g(E) \sqrt{\frac{2e}{m_e V_p}}$$

