3D investigations of a radio-frequency plasma with a Langmuir Probe

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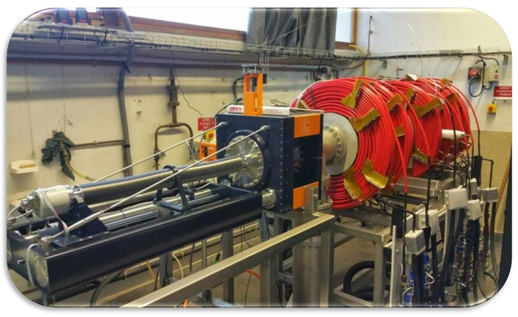
Overview: ALINE, a link between theory and experiments

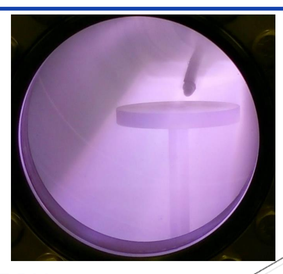
The ALINE device has the goal to study Radio Frequency (RF) sheaths in magnetized plasmas. Thanks to its design, the plasma is easily accessed by diagnostics so that electric potential, temperature, densities are accurately measured.

The stability and reproducibility of the plasmas, together with the local competences in Particle in Cells and Vlasov modelling, makes the Aline Experiment a great opportunity for a direct link between theory and experiment in sheath physics…



The ALINE device

ALINE: Experimental Setup

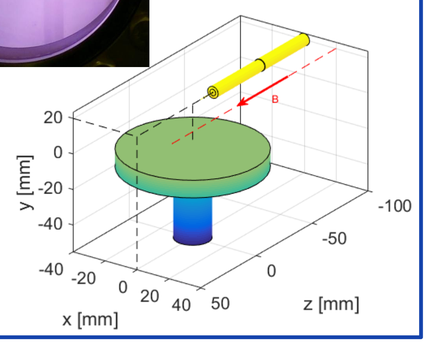


Chamber: 100cm x 30cm cylinder stainless steel
Gas: Ar/He/(H)

Plasma generation:
- Radio Frequency (RF): 600W @ 0,1-200MHz
- Electron Cyclotron Resonance (ECR): 3kW @ 2,45GHz

Plasma:
- Electron Temperature: 1-6 eV
- Density: 10^{14}-10^{18}m^{-3}
- Mean Free Path: 10^{-2}m -10^{-3}m

Magnetic field:
- 3 x 2 Coils for a magnetic field up to 0,1T



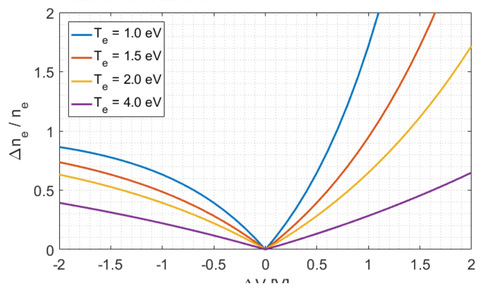
Langmuir Probe: How to choose the proper theory

Electron Current

❑ Electron population in a retarding field ($V_{probe} < V_{plasma}$)

$$I_e = A_{probe} e\,(2\pi m_e)^{-\frac{1}{2}}\,(n_e T_e)^{\frac{1}{2}} \exp\left(-\frac{eV_{plasma}}{T_e}\right)\exp\left(\frac{eV_{probe}}{T_e}\right)$$

$$\frac{\Delta n_e}{n_{e1}} = \frac{n_{e2} - n_{e1}}{n_{e1}} = \exp\left(\frac{e\Delta V}{T_e}\right) - 1$$



Ion Current

❑ Ion population in an attractive potential

$$I_i = e\,\frac{n_i}{2}\left(\frac{T_e}{M_i}\right)^{\frac{1}{2}} \times 2\pi l_{probe}\left(r_{probe} + \lambda_{sheath}\right)$$

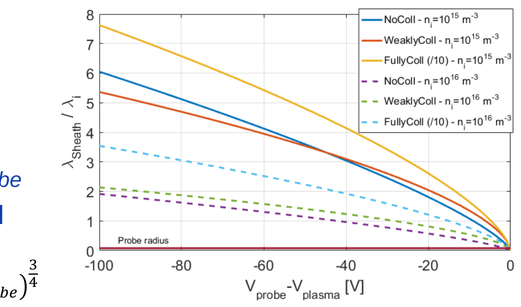
For a cylindrical probe

❑ Sheath size dependence with the applied potential

$$\lambda_{sheath}^{NoColl} = \frac{2^{\frac{5}{4}}}{3} \times e^{-\frac{1}{4}}\,\epsilon_0^{\frac{1}{2}} \times \left(n_i\,T_e^{\frac{1}{2}}\right)^{-\frac{1}{2}} \times \left(V_{plasma} - V_{probe}\right)^{\frac{3}{4}}$$

$$\lambda_{sheath}^{WeaklyColl} = \left(\frac{5}{3}\right)^{\frac{3}{5}}\left(\frac{8}{9\pi}\right)^{\frac{1}{5}} e^{-\frac{1}{5}}\,\epsilon_0^{\frac{2}{5}} \times \lambda_i^{\frac{1}{5}} \times \left(n_i T_e^{\frac{1}{2}}\right)^{-\frac{2}{5}} \times \left(V_{plasma} - V_{probe}\right)^{\frac{3}{5}}$$

$$\lambda_{sheath}^{FullyColl} = \left(\frac{9}{8}\right)^{\frac{1}{3}} \epsilon_0^{\frac{1}{3}} \times T_i^{-\frac{1}{6}} \times \lambda_i^{\frac{1}{3}} \times \left(n_i\,T_e\right)^{-\frac{1}{6}} \times \left(V_{plasma} - V_{probe}\right)^{\frac{2}{3}}$$

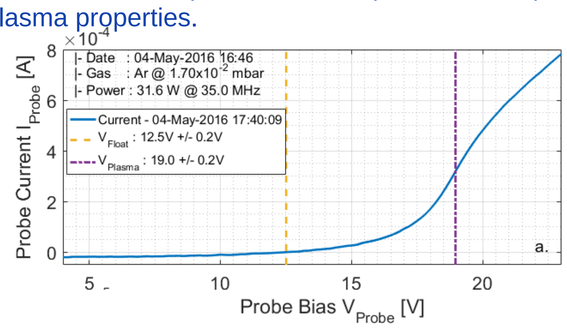


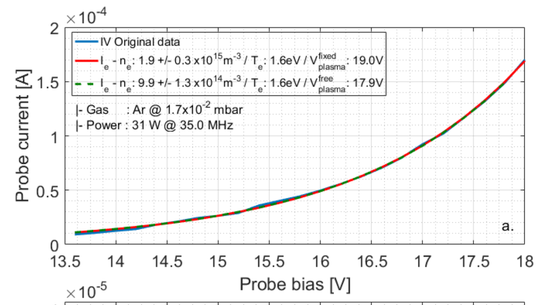
❑ Simulations suggest geometrical effects

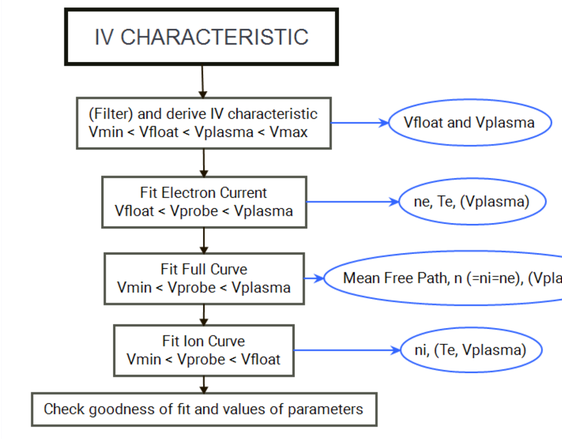
⇒Cylindrical to spherical sheath shape with increasing applied potential

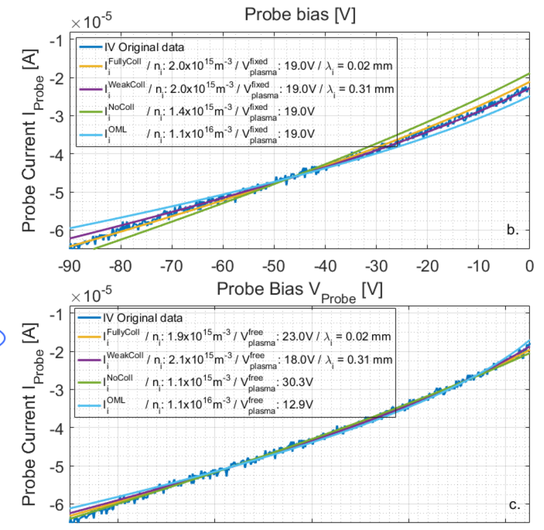
Langmuir Probe: How to apply the proper theory

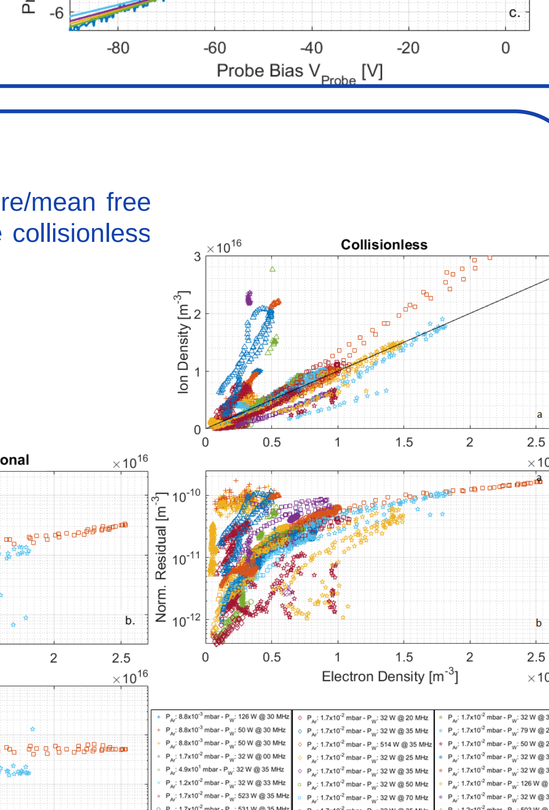
As some of the parameters appear coupled in the different formula (e.g. V_{plasma} and n_e), the order of the different fit procedure is of paramount importance to get reasonable values for the different plasma properties.







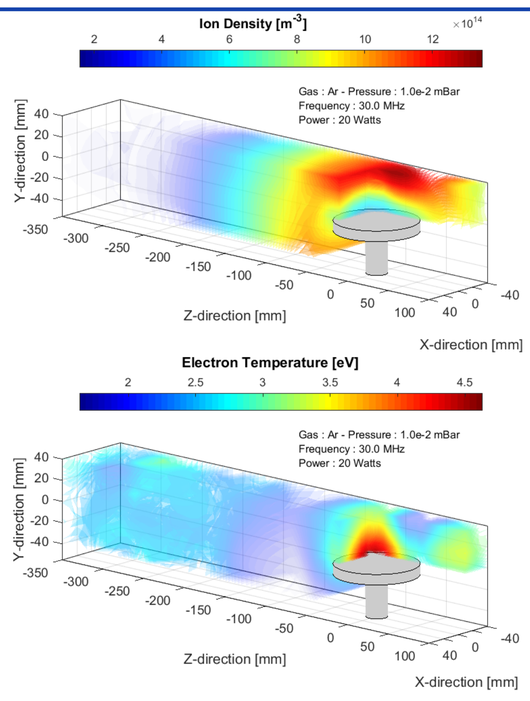


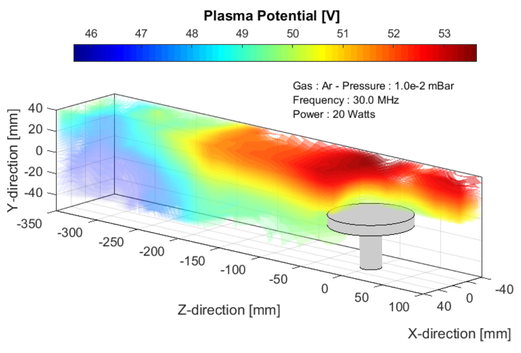


Plasmas in 3D

Remote arm:
- allows scans in the three space dimensions
- accuracy < 0,1mm in positioning
- maps of 3-4000 points (~3 hours)

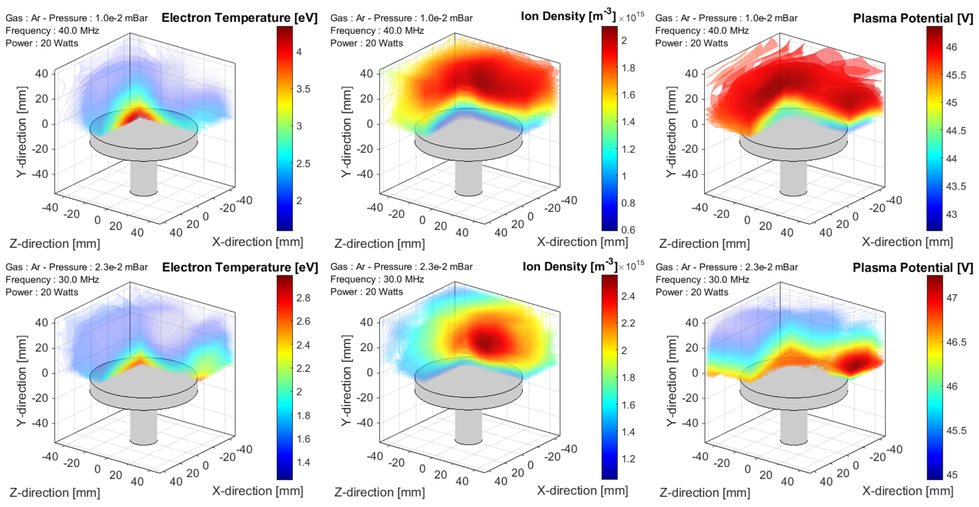
Plasmas properties:
- Gradients can be studied over tens of cm
- 3D structures clearly observed
- Suspicion of probe/antenna interactions for Z>0





Plasma shaping

The “shape” of the plasma on top of the RF antenna is affected by the discharge parameters. With a slight modification of the neutral pressure and excitation frequency, plasma with comparable densities but different shapes can be achieved.



Different collisional regimes

Plasmas in ALINE cover different range of pressure/mean free path for the ions. Hence, the sheath can either be collisionless or weakly collisional for the ions.

Pressure Ar	Mean Free Path
2,4x10^{-2} mbar	2,4mm
3,2x10^{-3}mbar	19,8mm
9,2x10^{-4}mbar	69,7mm

What’s next ?

❑ Interpretation of IV in B field…

❑ Development of a tiltable antenna

❑ Test of new cathode shape designs

New cathode Design : NCC 1701