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# Langmuir wave excitation in a small-scale laboratory plasma: a model for solar wind


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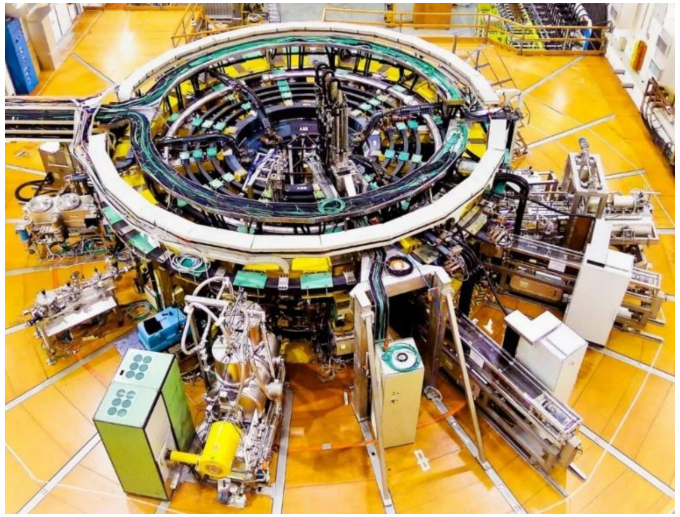
Consorzio RFX

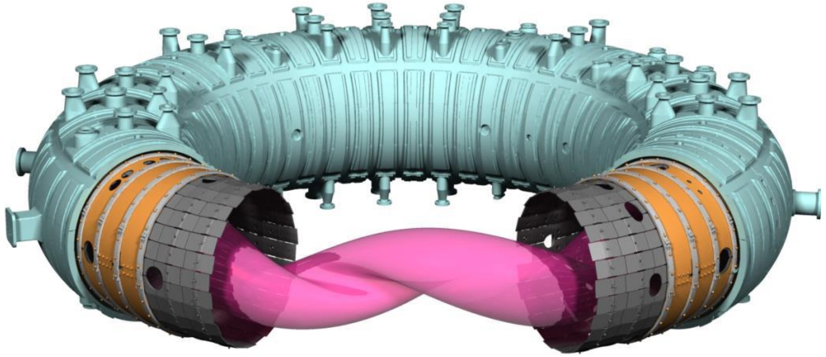

NORDITA Workshop, Stockholm 11-29 May 2026

# Consorzio RFX* in Padova, Italy

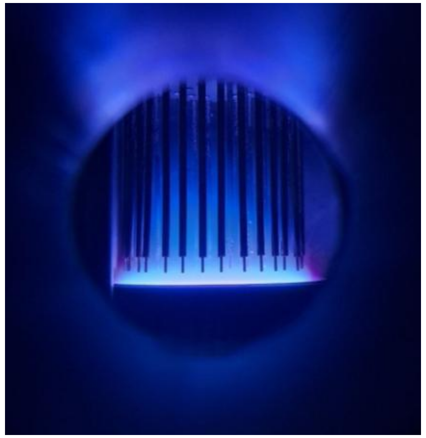
* CNR, ENEA, INFN, Università di Padova, Acciaierie Venete SpA

RFX-mod2






Cold plasma experiments



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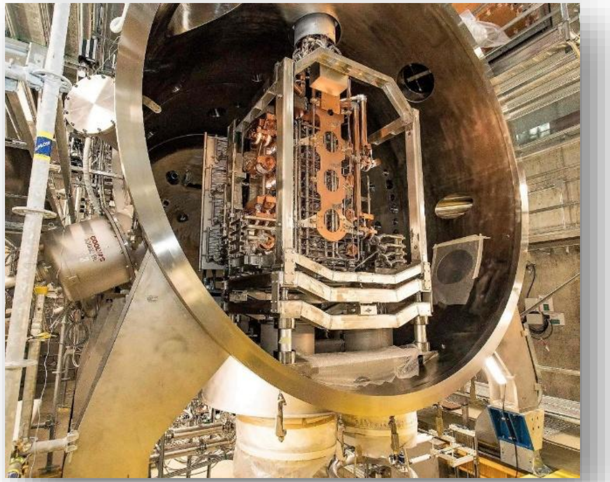
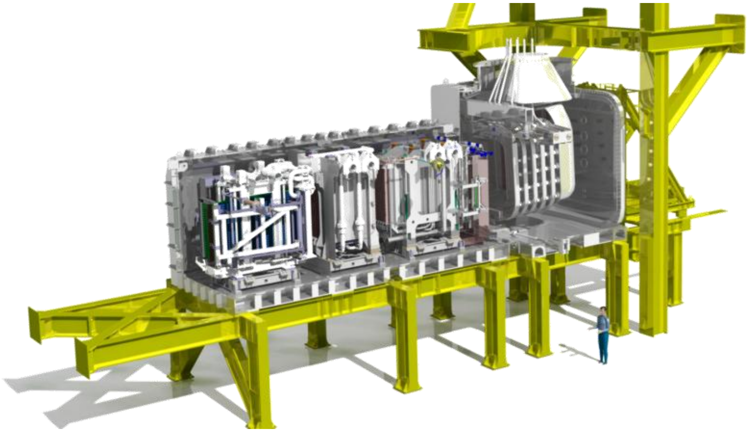


MITICA



# Langmuir wave excitation in a small-scale laboratory plasma: a model for solar wind

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# Motivation & Objectives

- Observations in space

| Space | Theory | Experiment | Numerical |
|---|---|---|---|
| • Observations of Langmuir waves and electron beams in **solar wind**<br>• Type III radio burst<br>• Excitation of Langmuir waves in magnetic holes | • Bump-on-tail instability<br>• Bohm-Gross dispersion relation<br>• Cherenkov Resonance condition $\omega \approx \kappa v_b$ | • Background thermal plasma: ionization of gas<br>• Suprathermal electron beam: thermionic emission<br>• Diagnostic tools<br>• High temporal resolution measurements of fluctuation | • 1D-1V Vlasov-Poisson solver<br>• Time evolution of distribution function and of electrostatic potential<br>• Mirrors experimental set-up |

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- Theoretical basis
- Replicate in small laboratory plasma
- Compare theory, observations, and simulations

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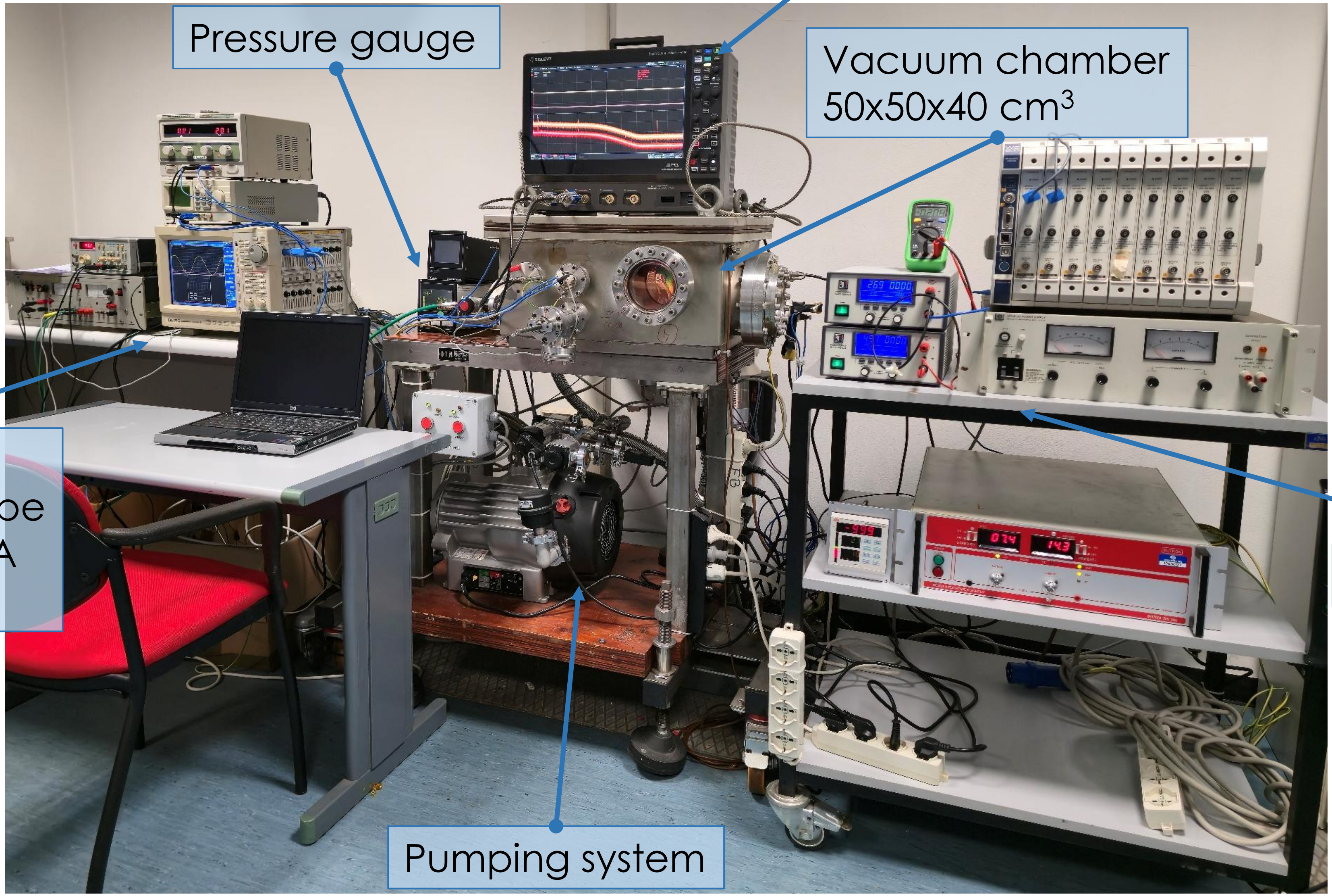
# Experimental set-up



Oscilloscope (20 Gs/s, 3 GHz bandwidth)

Pressure gauge

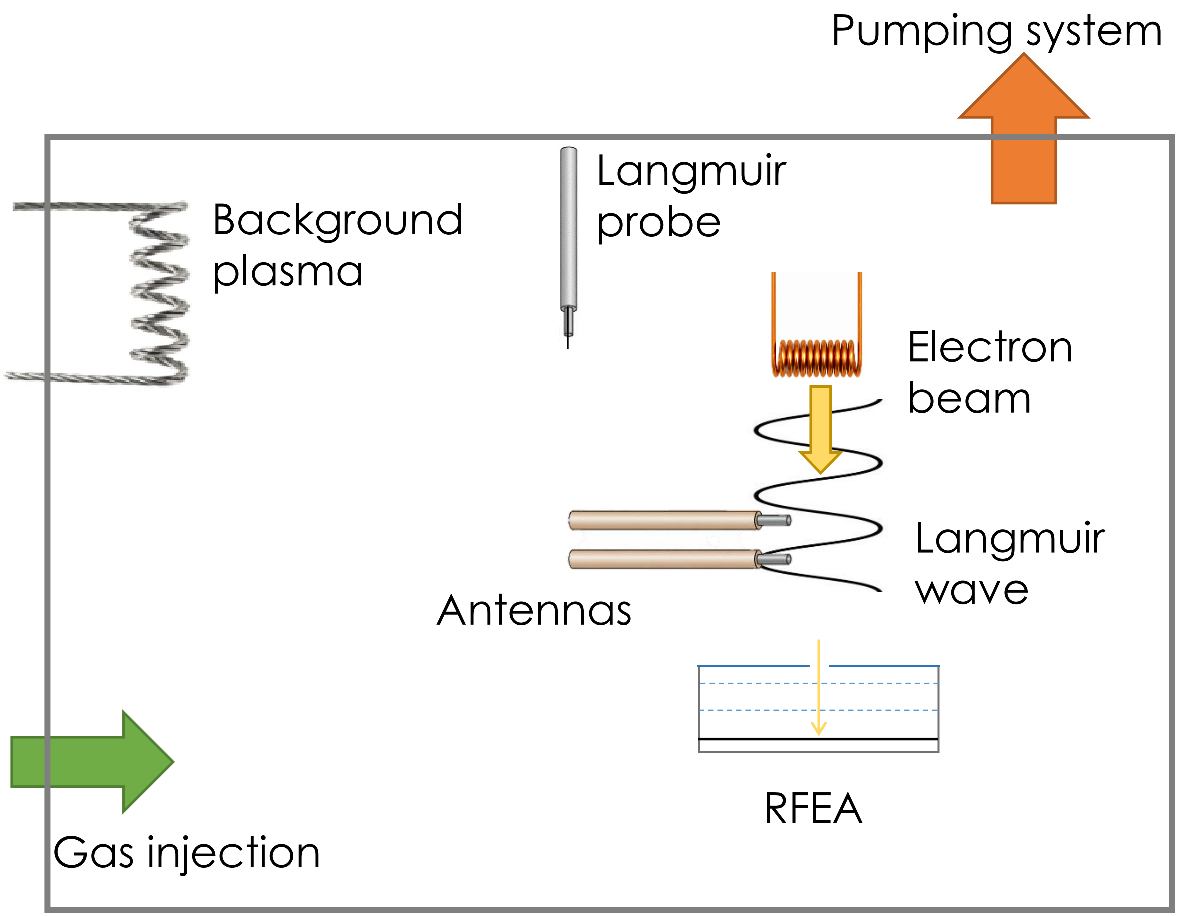
Vacuum chamber 50x50x40 $cm^3$

Power supply and oscilloscope for LP and RFEA acquisition

Power suppliers

Pumping system

# Experimental set-up – inside vacuum chamber




| | |
|---|---|
| Argon pressure | $2 - 5 \cdot 10^{-3}$ mbar |
| Background density $n_e$ | $5 \cdot 10^{15} - 2 \cdot 10^{16}$ $m^{-3}$ |
| Plasma frequency $f_{pe}$ | 600 – 1200 MHz |
| Electron temperature $T_e$ | 2 eV |
| Electron beam density $n_b$ | 1 – 5 % $n_e$ |
| Electron beam velocity $v_b$ | $> 2\, v_{th,e}$ |
| Electron beam temperature $T_b$ | 1 – 10 % $T_e$ |

All these parameters can be modulated !

# Collisionless approximation

- The difference in collisional regime between space and lab plasmas is one of the main difficulties
- Low degree of ionization -> collisions with neutrals dominant

$\nu_{ei} \approx 0.2$ MHz

$\nu_{en} = n_n \langle \sigma_{en}\, v_e \rangle \approx 2$ MHz

$\lambda_{mfp} = {}^{v_{th,e}}/_{\nu_{en}} \approx 0.4$ m

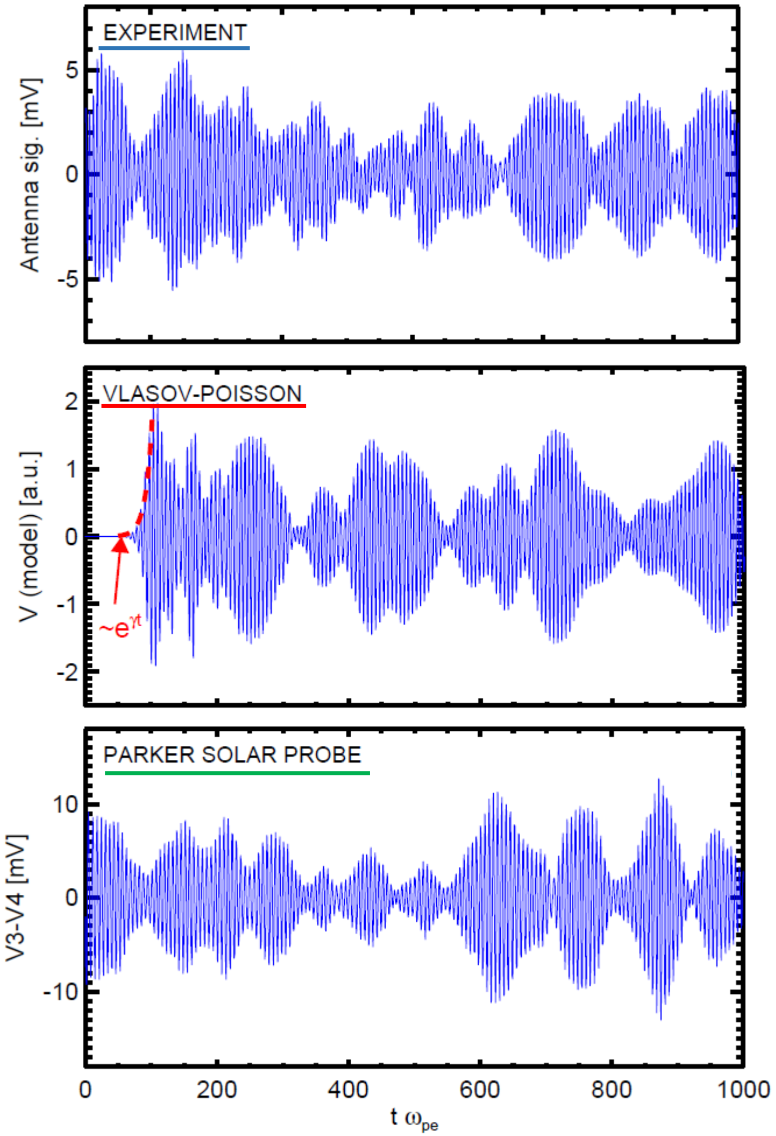
${}^{\nu_{en}}/_{f_{pe}} \approx 10^{-3}$

${}^{\lambda_{mfp}}/_{\lambda_\omega} \approx 10^2$

- Valid approximation because large separation between the collision and the beam-induced Langmuir-wave frequencies
- Simulation are performed under the assumption of collisionless dynamics

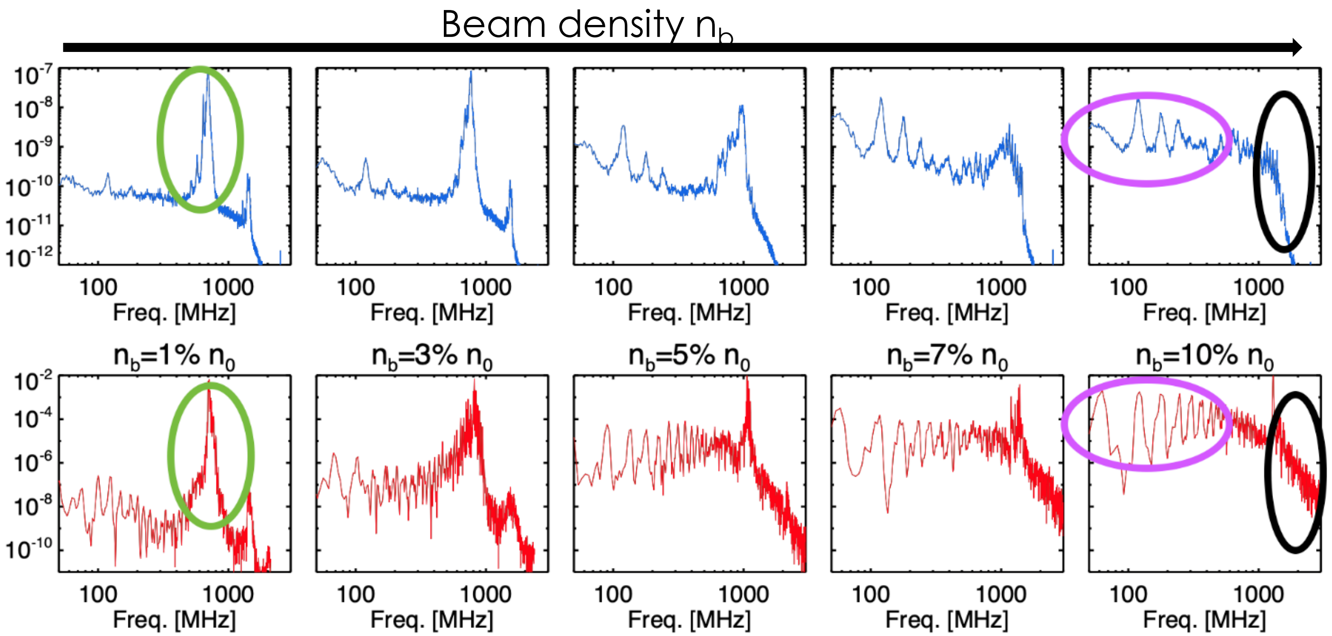
# Results – dynamical behaviour

- Experimental, model, and in-situ spacecraft data
- Consistent dynamical behavior: structure of wave packets and their modulation.
- Exponential growth, followed by saturation and damping



# Results – spectra

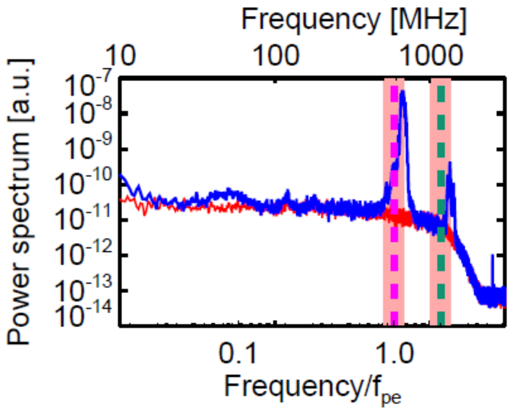
- Close match between experimental, numerical, and in-situ measurements spectra
- Threshold in $v_b$ to excite the wave
- At increasing $n_b$, lower frequency beam induced modes arise



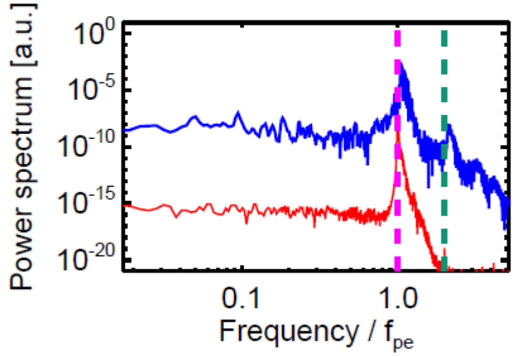

Experiment

Vlasov - Poisson

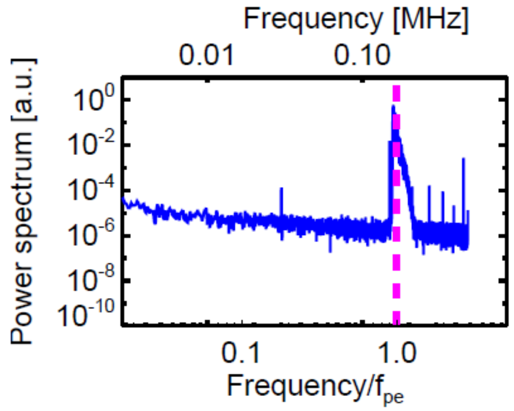
Experiment




Vlasov - Poisson

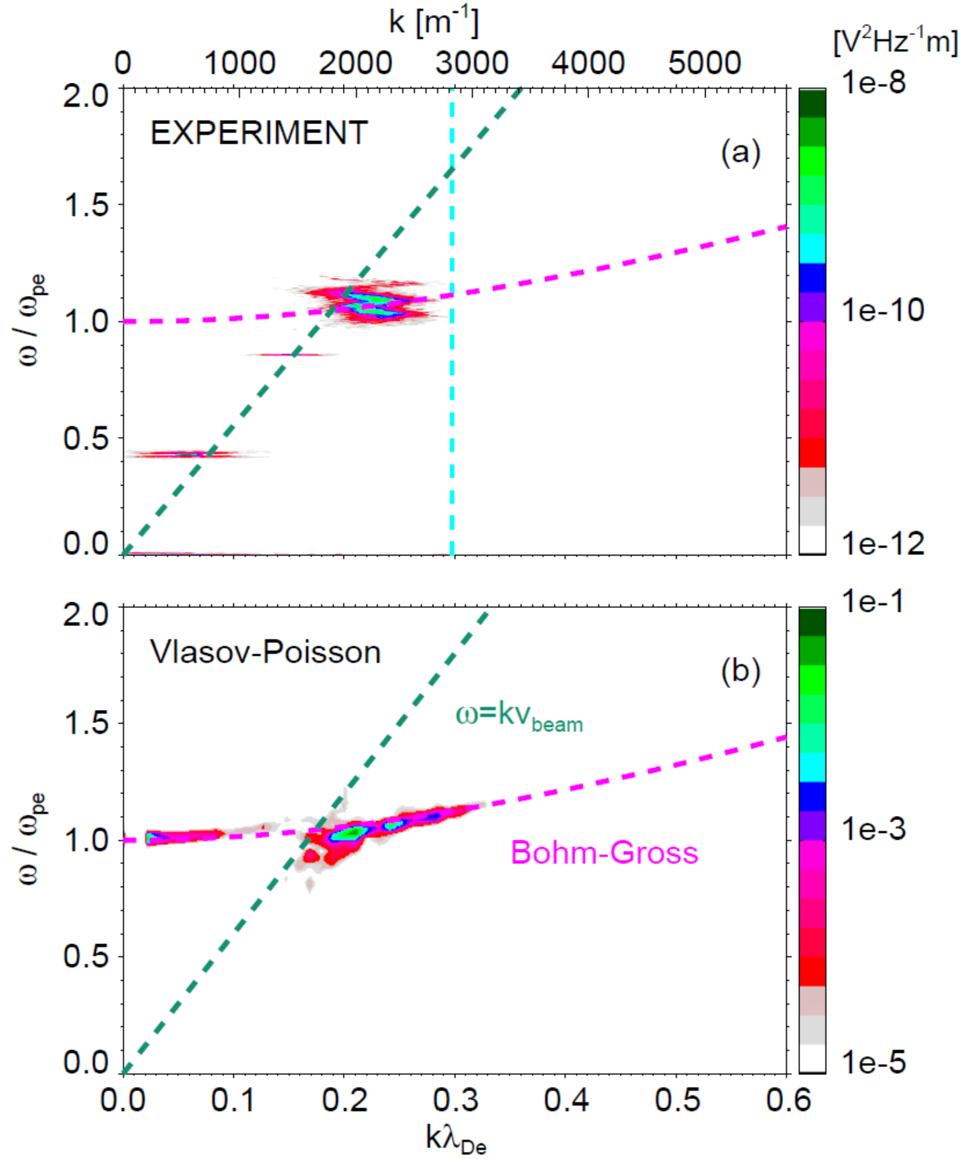



Parker Solar Probe



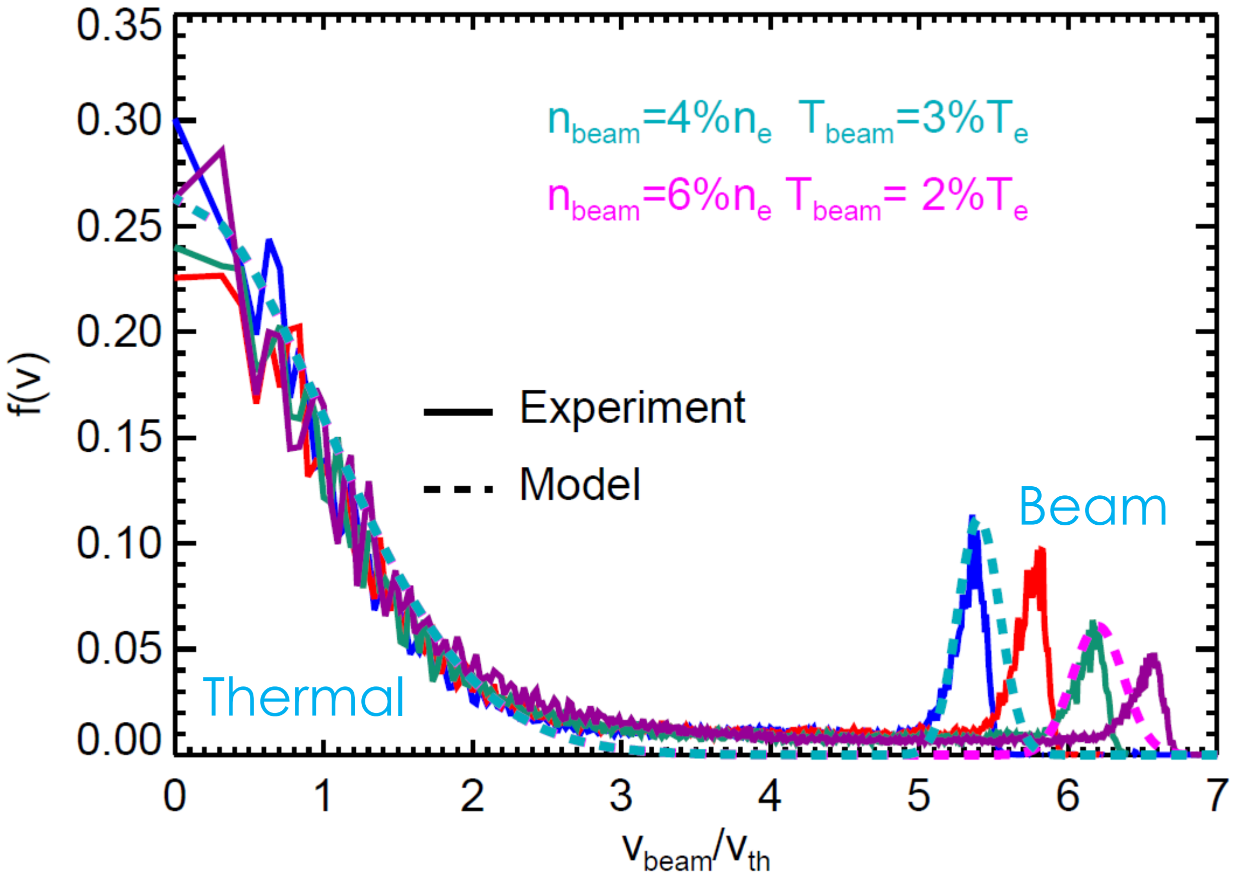
# Results – ω-k spectra

- k is measured experimentally: multi-point measurement by the use of 2 antennas
- Mode aligns with Bohm-Gross dispersion relation at resonance condition
- Experimental measurements and simulation find the same wave vector (normalized to $\lambda_D$)



# Results – electron distribution

- Reconstruction of the electron velocity distribution function
- Thermal and beam electrons
- Out of equilibrium: collision are too slow
- Tuning $n_b$ , $v_b$ , $T_b$

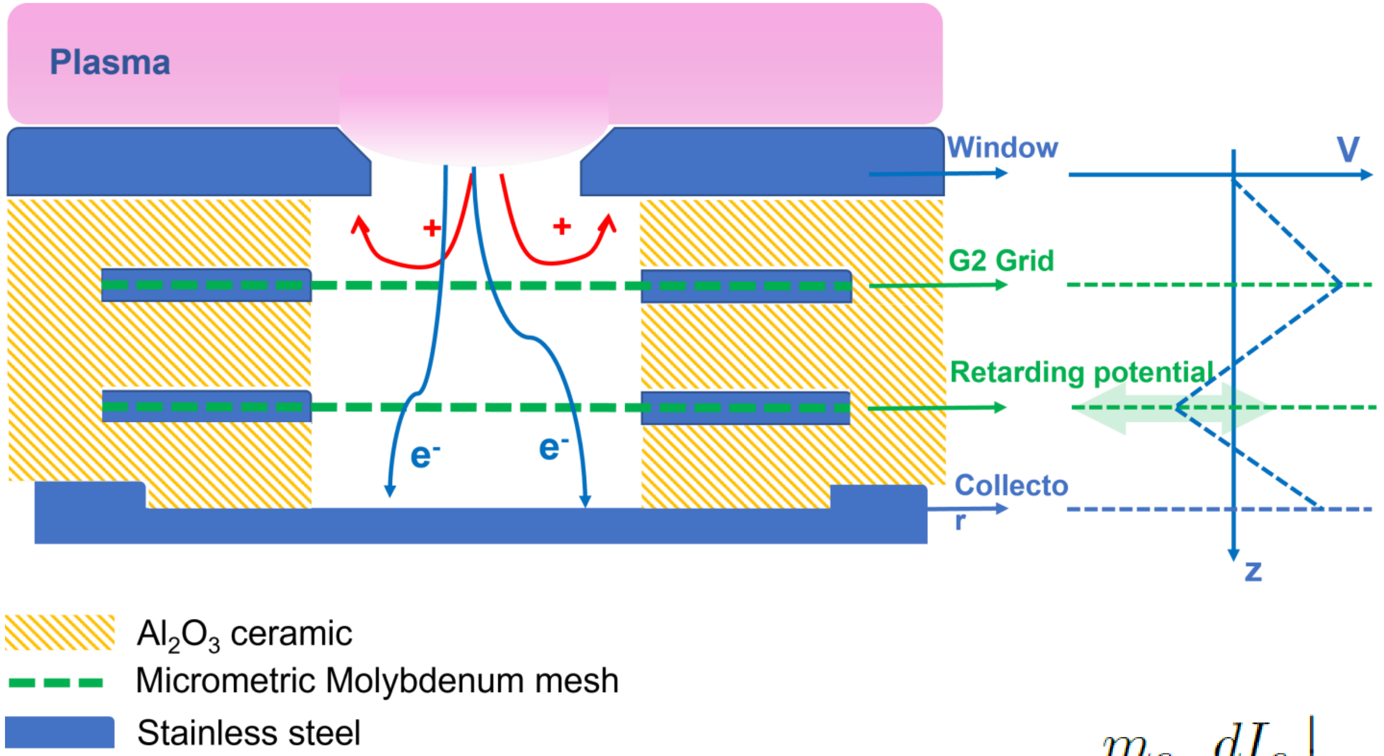


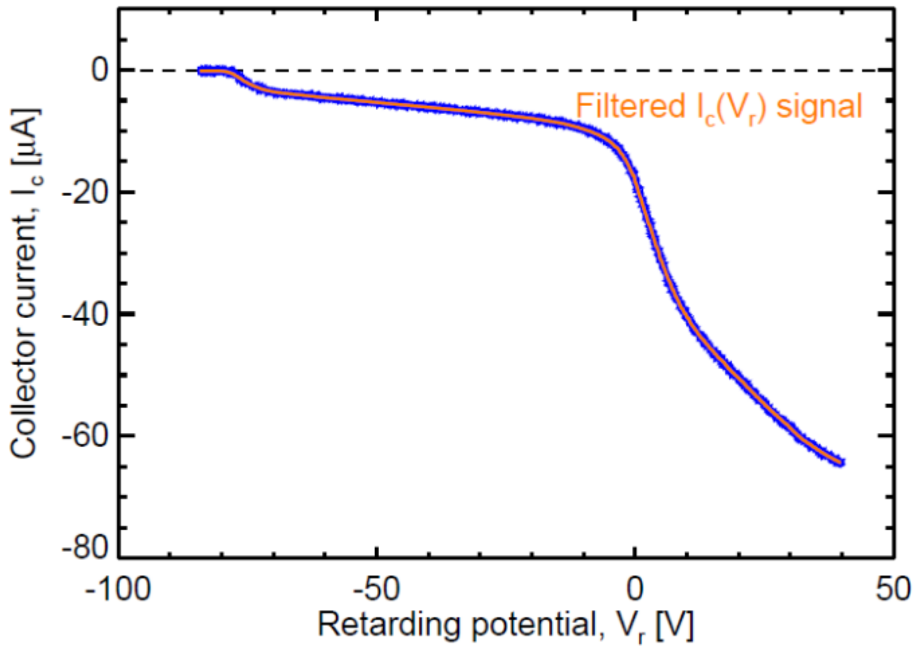
# Conclusions

- We built a laboratory system with full control on the parameters affecting the beam-driven wave excitation phenomena and high diagnostic capabilities
- It is an example of **synergy between space and laboratory plasma physics to understand fundamental plasma processes**
- Experimental beam-plasma systems can serve as effective analogues for understanding wave-particle interactions in astrophysical environments
- Under certain condition, lab plasmas can be considered in the collisionless approximation, allowing for a comparison with phenomena happening in collisionless space plasmas, such as the solar wind

# Back up slides

# Retarding Field Energy Analyzer

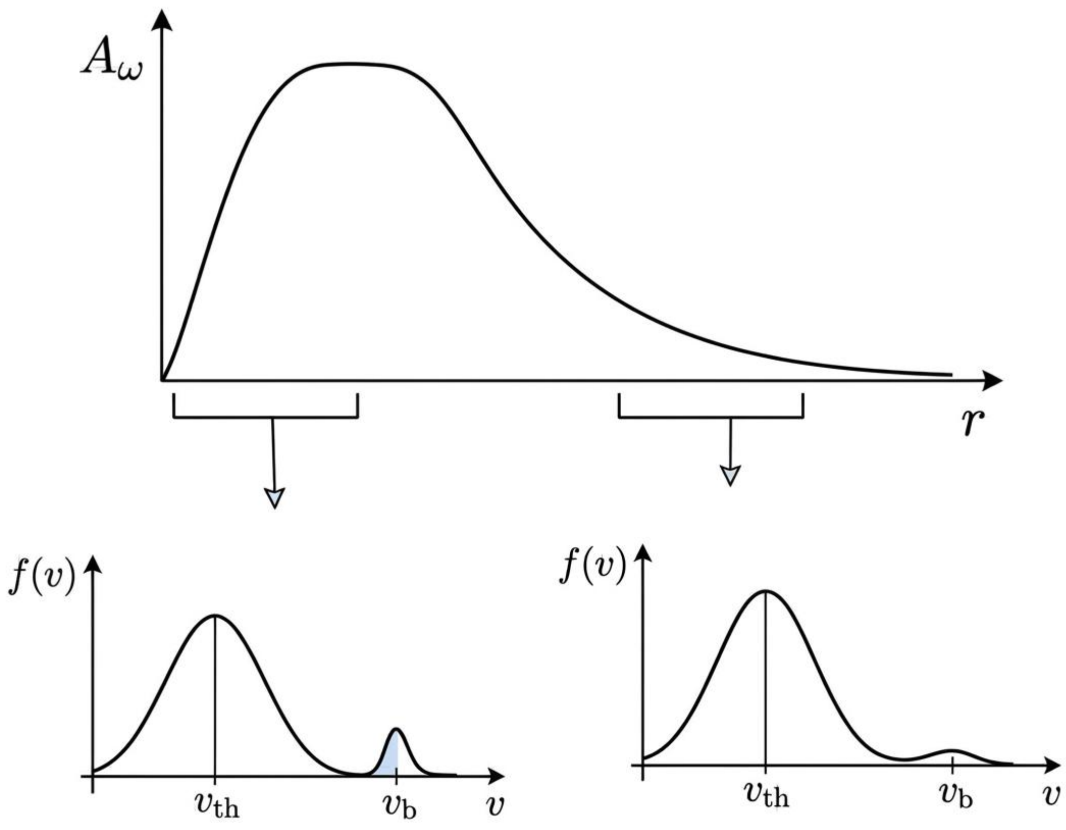



$$f_v(v) = -\frac{m_e}{e}\,\frac{dI_c}{dV_r}\bigg|_{V=\frac{mv^2}{2e}}$$

# Beam-plasma interaction

- Energy transfer from electron beam to wave
- Wave damping due to missing source
- In time we keep the source on, the wave is continuously excited, but in space it is dumped because the positive derivative part is not present



# Langmuir wave peak – scan in $n_b$