Mutual impedance experiments as a diagnostic for magnetized space plasmas

Pietro Dazzi [1,2], Pierre Henri [1,3], Francesco Califano [4], Luca Bucciantini [1], Federico Lavorenti [3,4], Gaëtan Wattieaux [5]

[1] LPC2E, CNRS, Univ. Orléans, CNES, Orléans; [2] LESIA, Observatoire de Paris; [3] Laboratoire Lagrange, Observatoire de la Côte d'Azur; [4] Dipartimento di Fisica "E.Fermi", Universita di Pisa; [5] Laboratoire; Plasma et Conversion d'Energie, Université de Toulouse, CNRS

Mutual impedance experiments are a type of active, in-situ plasma diagnostic. They have shown their effectiveness by providing measurements of the electron density and temperature onboard Earth ionospheric missions, and later onboard the Rosetta cometary mission. Such instruments measure the mutual electrical impedance between two electric antennas embedded in the plasma to be diagnosed. The mutual impedance is itself a function of the plasma parameters, such as the plasma density and electron temperature. Current state-of-the-art numerical models of the measured mutual impedance provide access to these plasma parameters, under the assumption of an unmagnetized plasma. However, the magnetic field is expected to significantly impact mutual impedance measurements performed in magnetized plasma such as, e.g., in the magnetosphere of Mercury and Ganymede, respectively targeted by the BepiColombo and JUICE missions. The goal of this work is to extend mutual impedance instrumental models in order to take into consideration the effects of the magnetic field present in such magnetized planetary plasmas, to support those exploratory space missions. This is achieved by combining two complementary approaches: instrumental modeling and laboratory experiments. First, we have developed and validated a new numerical model, based on the calculation of the electric potential emitted by a spherical, point-like electric antenna in a magnetized, homogeneous, Maxwellian plasma. This new instrumental model is used to compute synthetic mutual impedance spectra and assess the impact of the electron magnetization on the instrumental response. We discussed plasma density diagnostics from the analysis of these synthetic mutual impedance spectra. Second, the plasma density diagnostic is used to analyze experimental results obtained in the controlled environment of the LPC2E plasma chamber PEPSO, which experimental setup has been upgraded for this study.

CONTEXT:

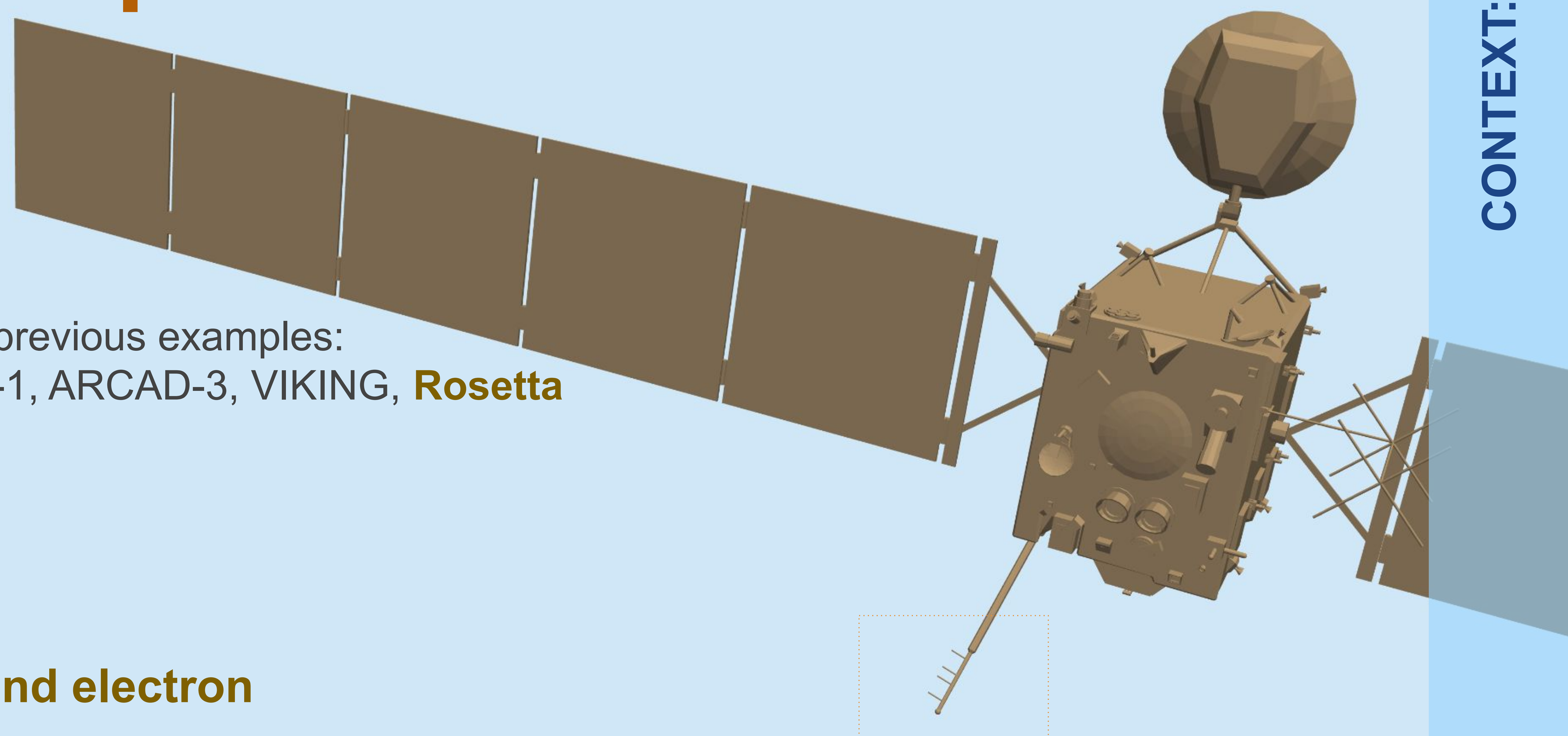
Different techniques for in-situ measurements of space plasmas:

- Particles:
  - Langmuir probes
  - Retarding potential analyzer
  - Particle spectrometer
  - …
- Fields:
  - Electric antennas
  - Fluxgate magnetometer
  - Search-coil magnetometer
  - …

Idea: use electric antennas to measure the plasma electrons distribution function moments.

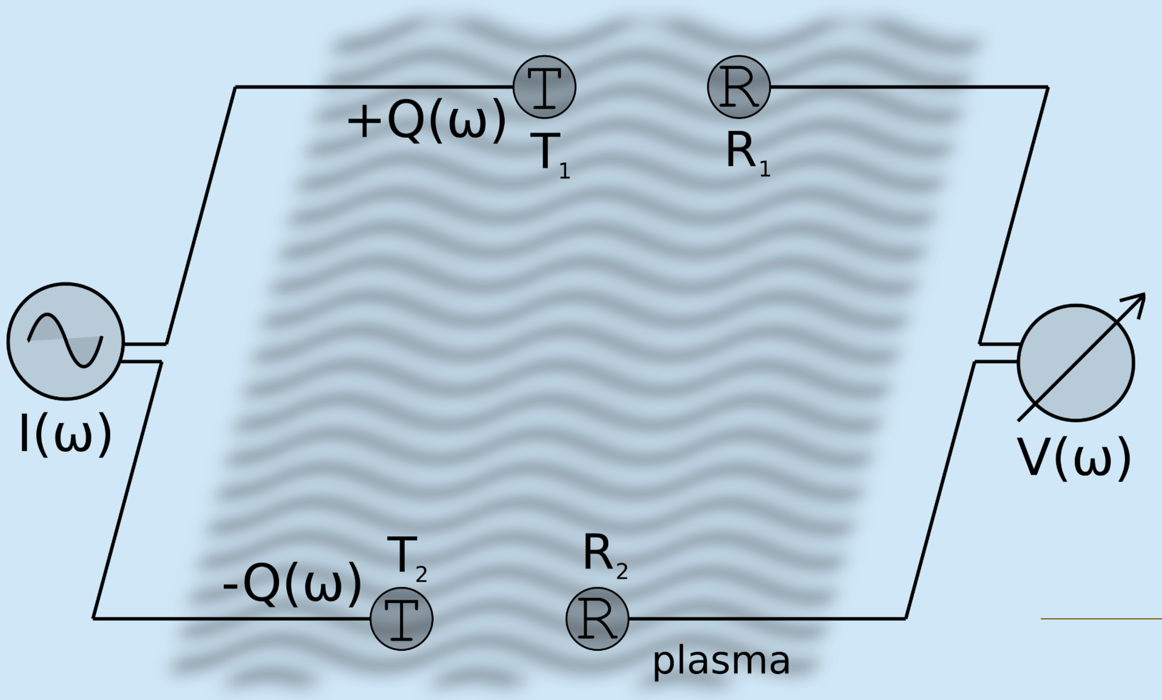
Mutual impedance experiments

*and quasi-thermal noise spectroscopy



Some previous examples:
GEOS-1, ARCAD-3, VIKING, **Rosetta**

Equivalent circuit for mutual impedance experiment, composed of two antennas, one emitting (T) and the other receiving (R).



Characteristics:

- active,
- in-situ,
- measure **plasma density and electron temperature**,
- different electron distribution functions.

$$Z(\omega) = \frac{V(\omega)}{I(\omega)}$$

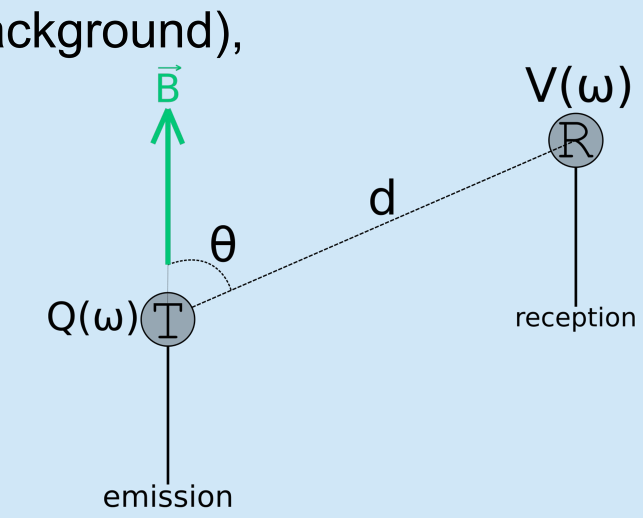
… same as studying the propagation of waves in the plasma!

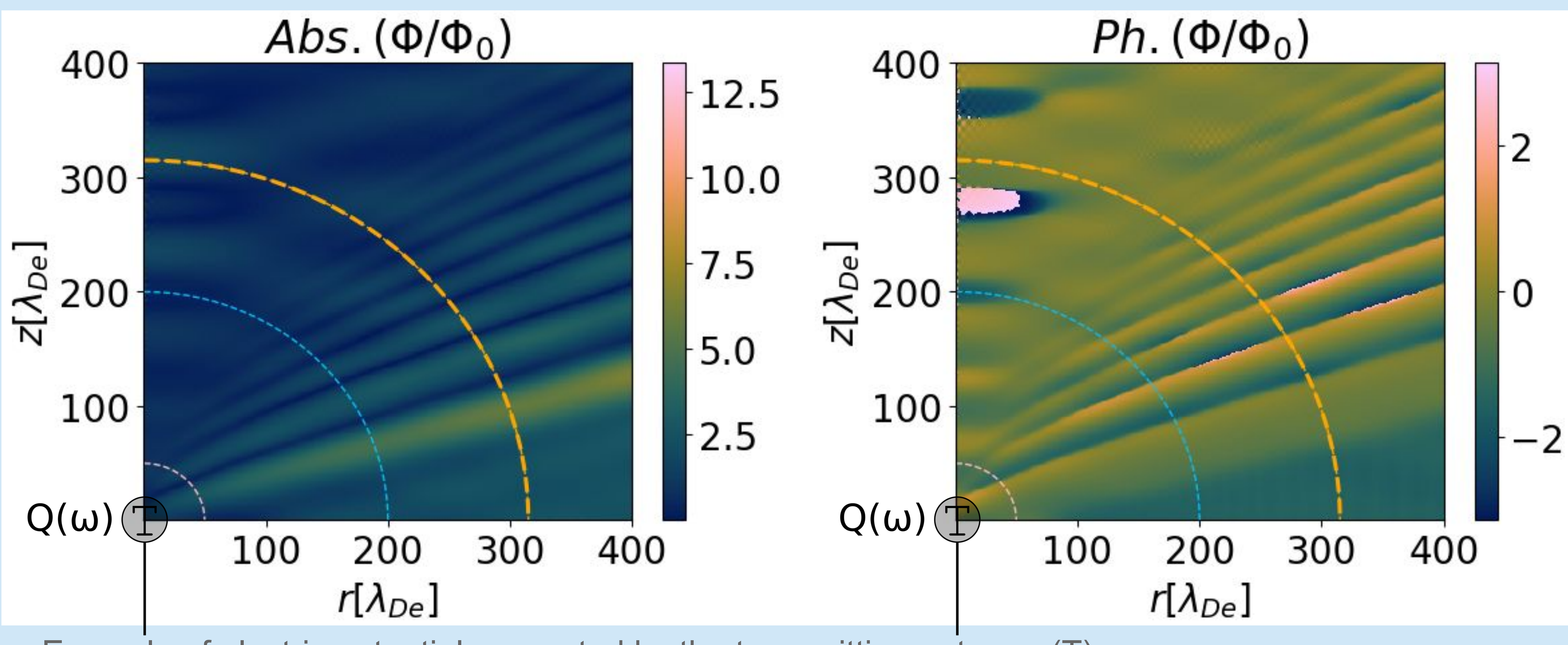
GOAL: We want to investigate the effect of an external magnetic field.

NUMERICAL RESULTS:

Model base on the hypothesis of:

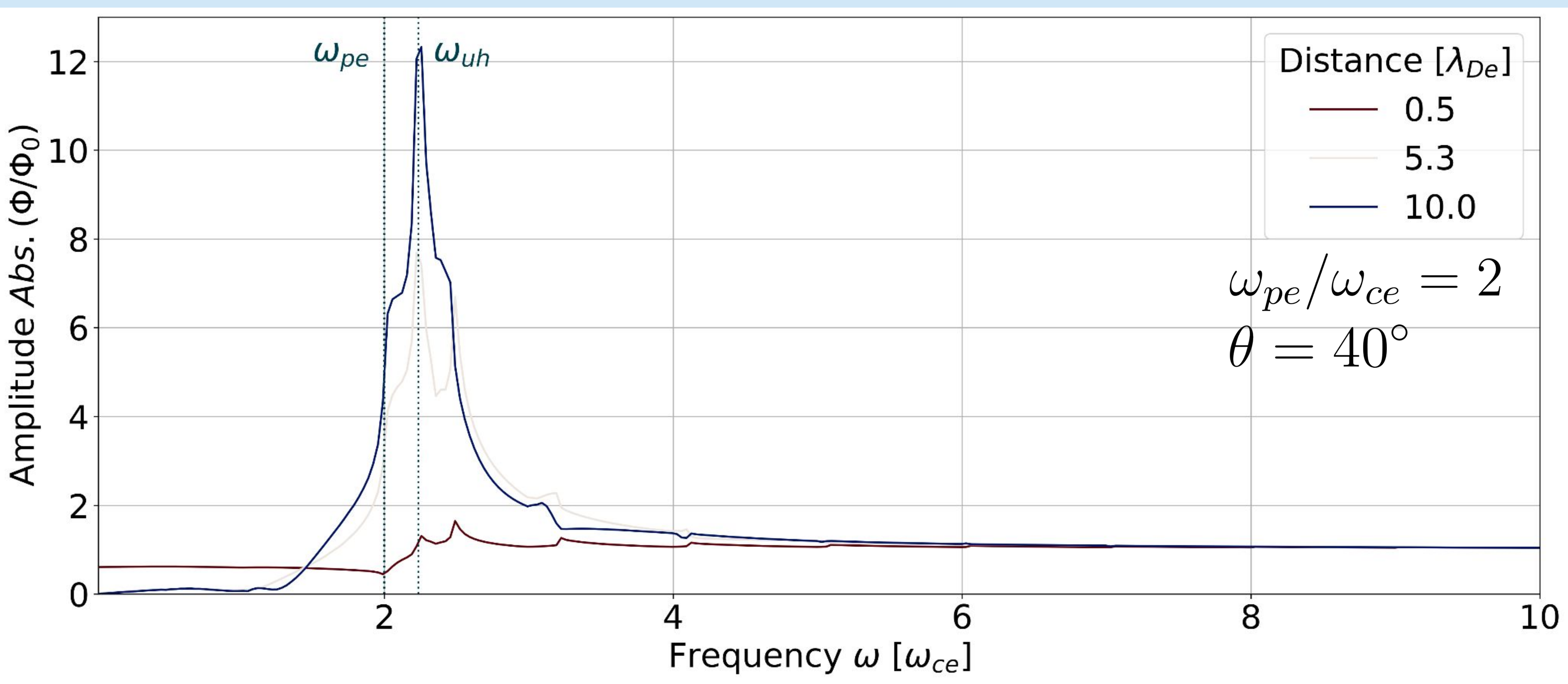
- **kinetic** (Vlasov) model,
- **immobile ions** (charge neutralizing background),
- **Maxwellian** electrons,
- **linear** approximation,
- **electrostatic** approximation,
- an oscillating **point charge**,
- uniform external **magnetic field**.

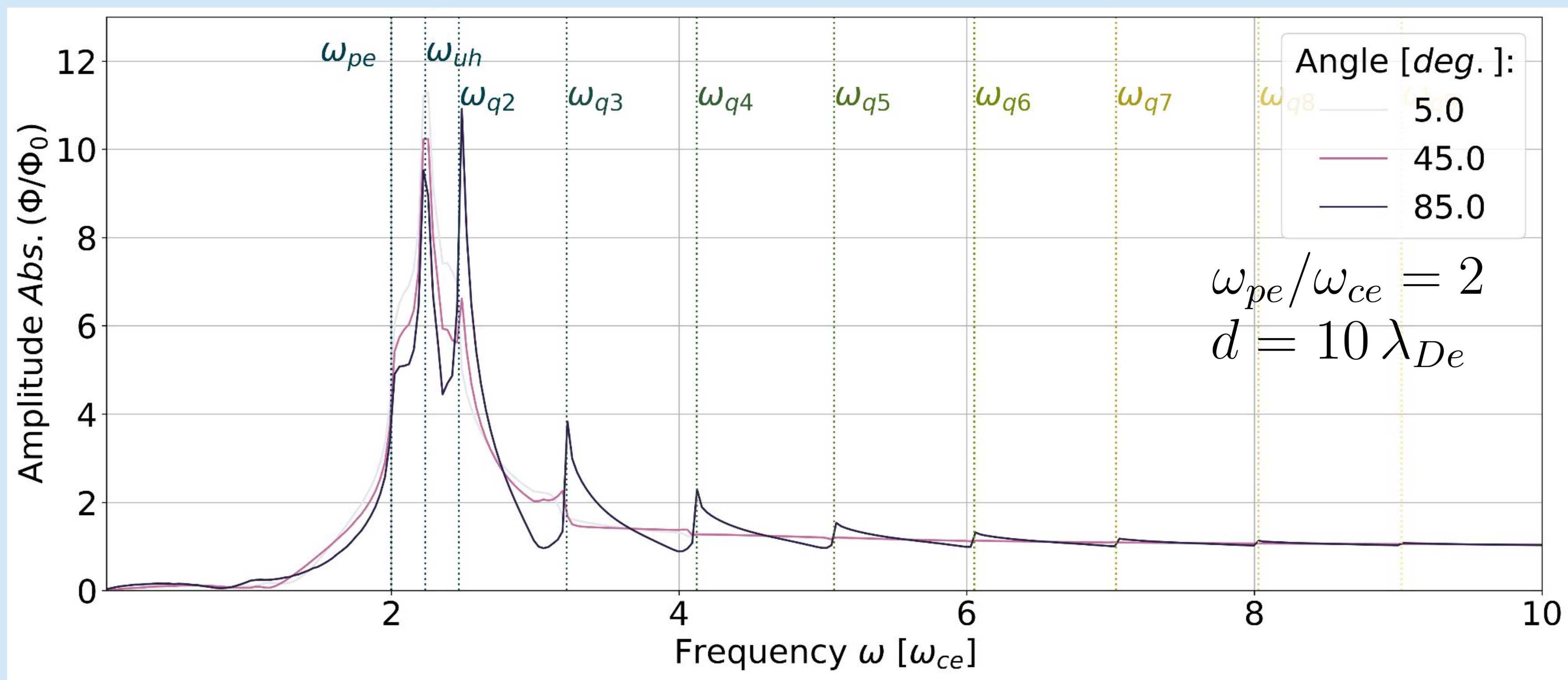




Example of electric potential generated by the transmitting antenna (T)

Spectra obtained from this calculation:

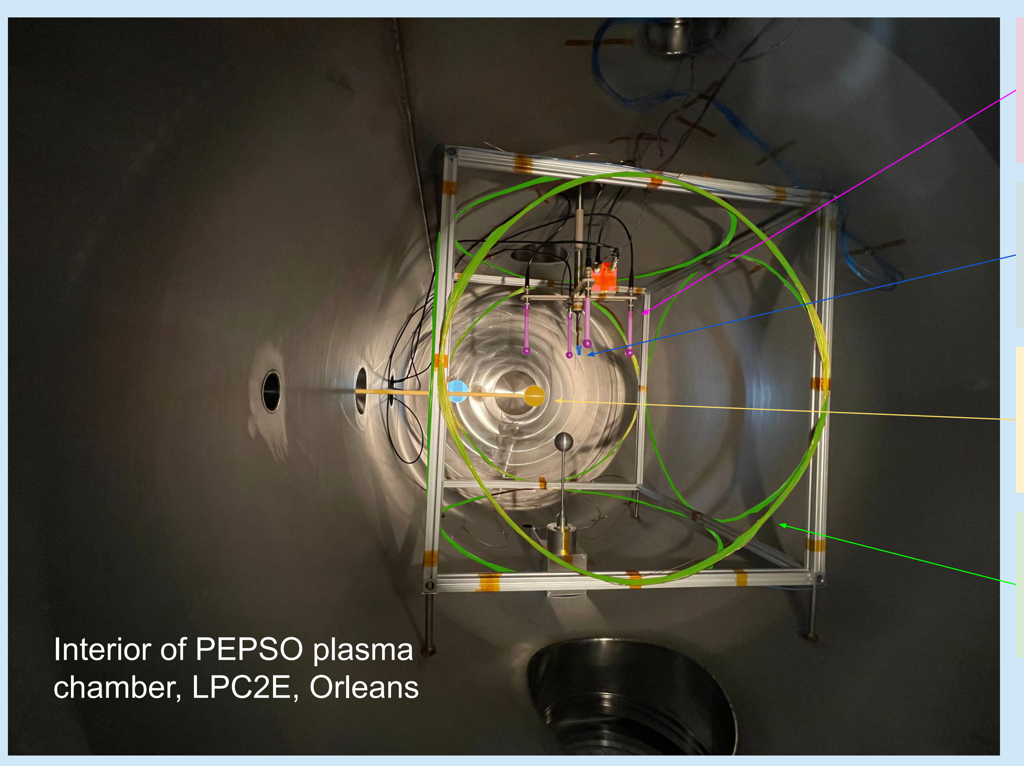




$f_{uh} \leftrightarrow n_e, B$ Diagnostic obtained from the spectrum maximum. $f_{qn} \leftrightarrow n_e, B$

EXPERIMENTAL RESULTS:

To validate this diagnostic, we compare this result with what is observed experimentally, in a plasma chamber setup developed during the course of this work.



Interior of PEPSO plasma chamber, LPC2E, Orleans

Mutual impedance

Magnetometer

Langmuir probe

Magnetic coils