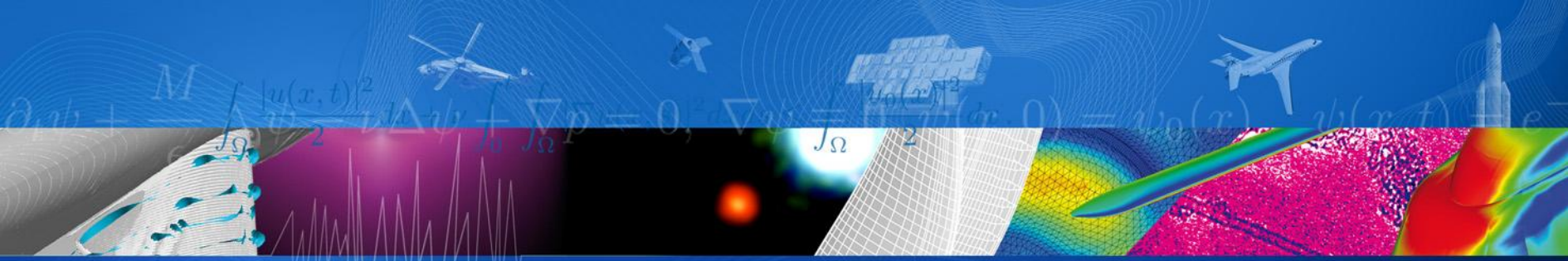

Experimental and Theoretical Characterization of an ECR plasma thruster

January 21th, PhD Day, LPP

PhD Student : F. CANNAT (DMPH/FPA)

ONERA Supervisor: J. JARRIGE (DMPH/FPA)

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return on innovation

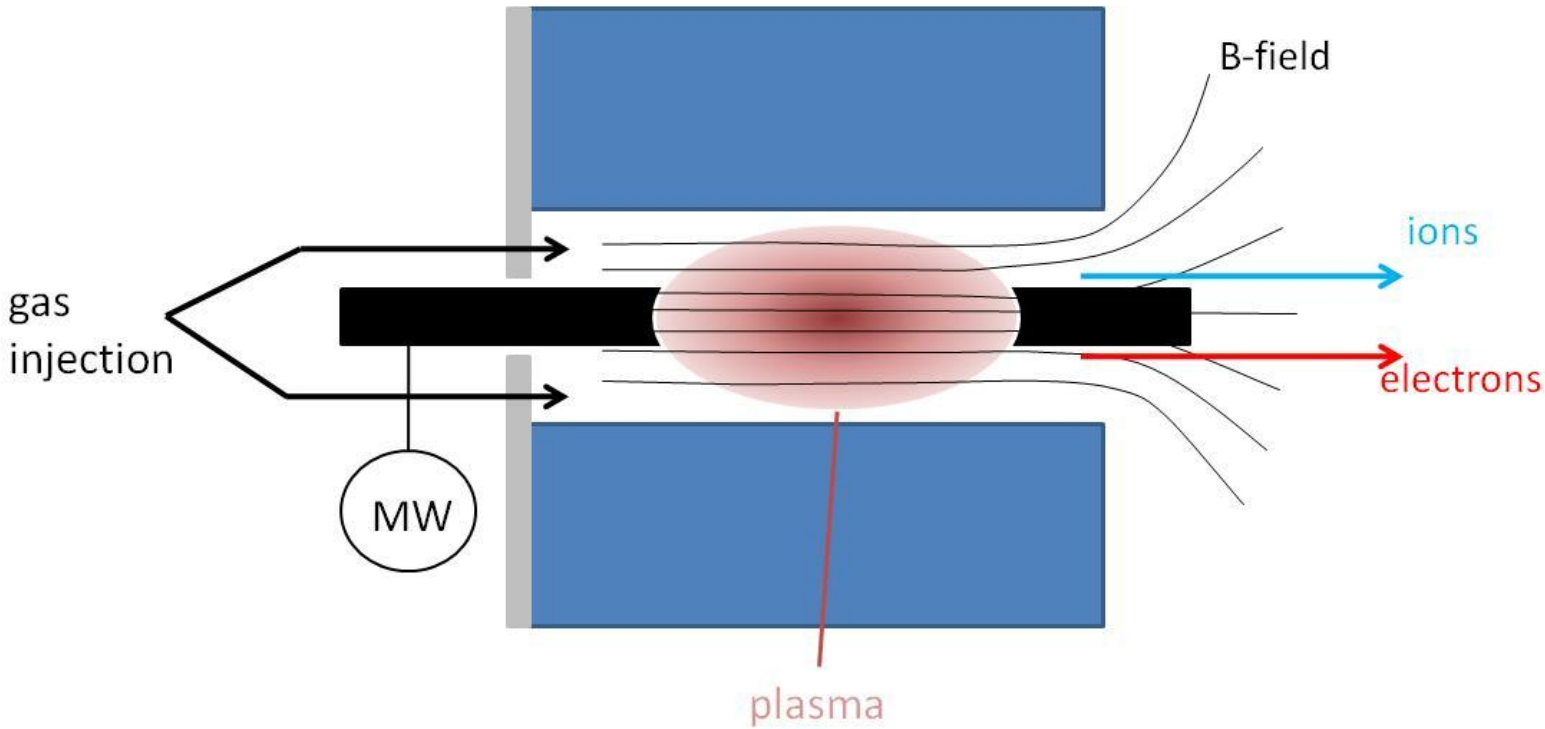
OUTLINE

- ECR Thruster : principle
- ECR Thruster : Experimental investigation
- ECR Thruster : Modeling

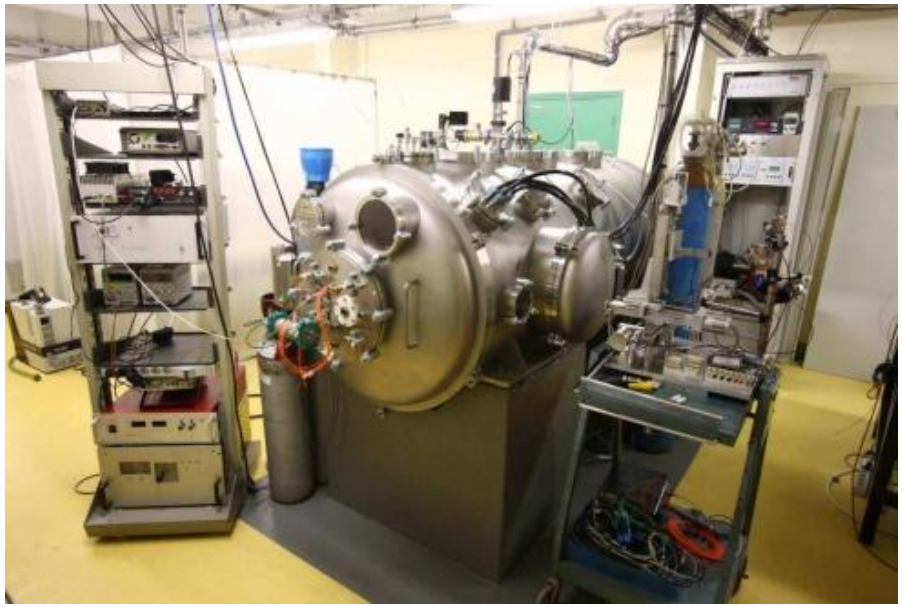
ECR principle

Principle of Electron Cyclotron Resonance (ECR) thruster.

- Coaxial geometry
- Electron heating by cyclotron resonance.
- Creation of a plasma by ionizing collisions.
- Acceleration of plasma in a magnetic nozzle.



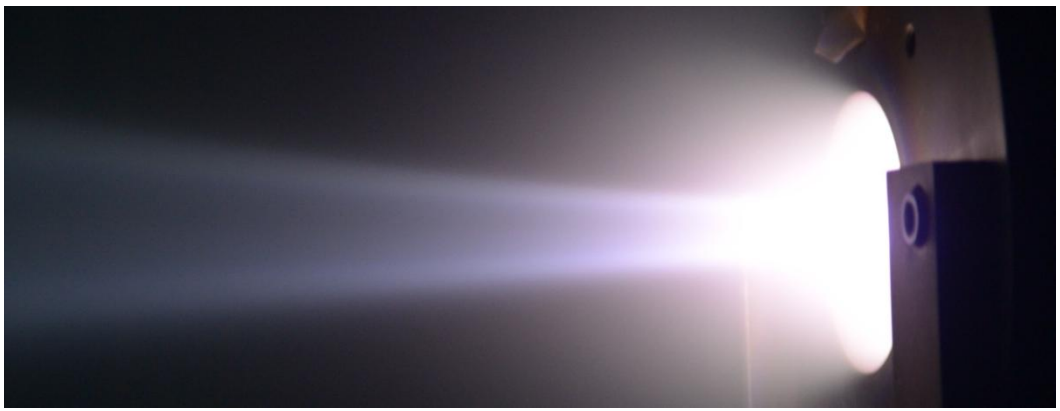
Vacuum Chamber & Plasma plume



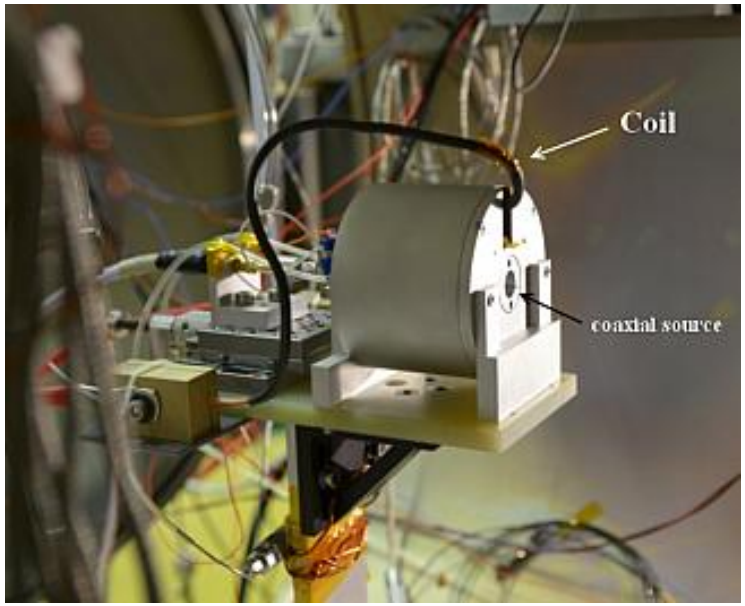
Vacuum chamber B09 (Palaiseau)
Pumping speed (3000L/s)

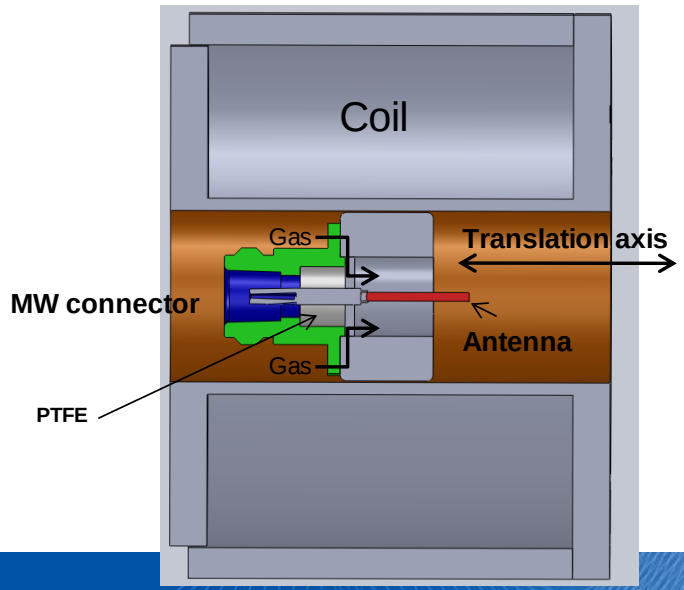
Operating pressure 10^{-5} mbar

Typical plasma plume

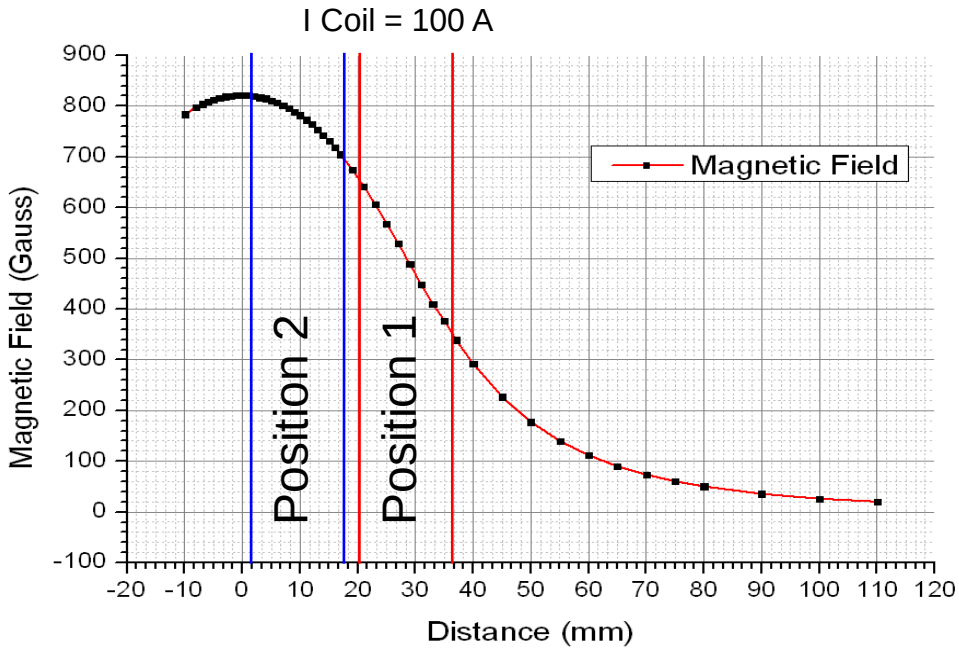


Magnetic field



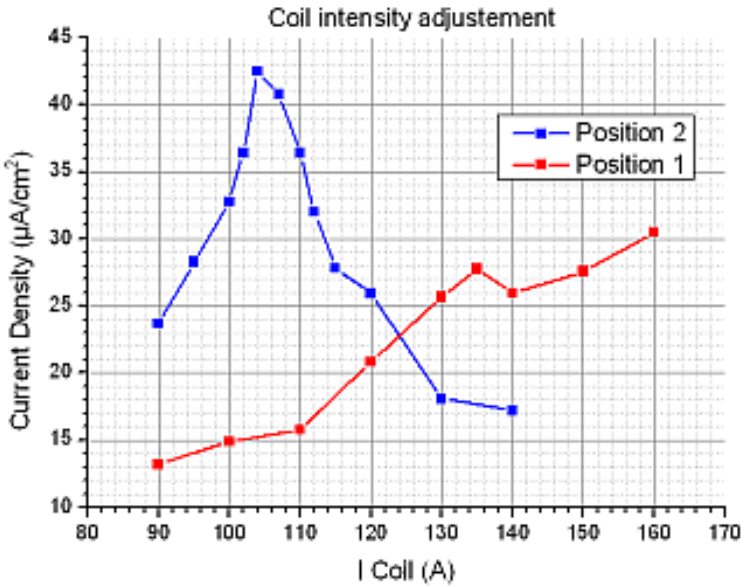


ECR Thruster – Coil version

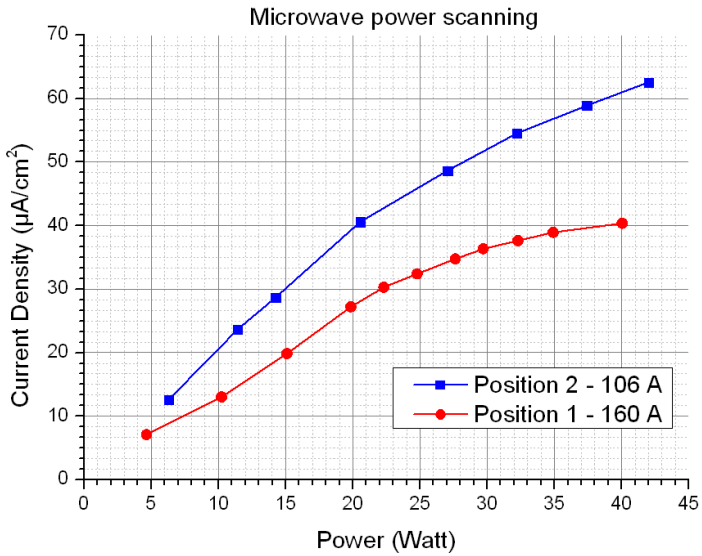


- Different magnetic gradient
- Different ECR position

Main results



Argon 0.1 mg/s – 22 Watts – 2.45GHz



Argon 0.1 mg/s – 2.45GHz

- Current density on ECR axis
- Faraday grid probe at 30 cm

Abstract has been accepted “Space Propulsion 2014” Cologne

Principal results

Current Performances

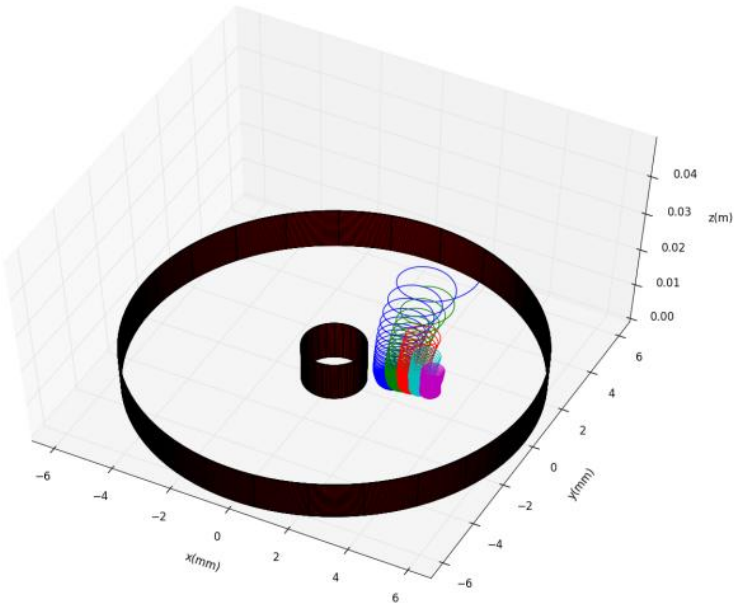
	Position 1		Position 2			
Gas	Argon		Argon	Xenon		
Mass Flow [mg/s]	0,1	0,2	0,12	0,06	0,1	0,1
Incident Power [W]	25	33	44	30	30	40
Ions Current[mA]	24,4	40,67	53,55	12,73	32	35,65
Ion Energy [eV]	175	90	170	300	120	140
η Mass utilization	10,1%	8,4%	18,5%	28,9%	43,6%	48,52%
ηenergy	17%	11%	21%	13%	13%	12,48%
ηdivergence	84%	77%	82%	83%	82%	79%
Thrust [mN]	0,25	0,27	0,52	0,30	0,47	0,55
Isp [s]	251	137	442	512	483	560
Thruster efficiency	1,22%	0,55%	2,57%	2,53%	3,76%	3,83%

$$\eta_{Mass\ utilization} = \frac{\dot{m}_i}{\dot{m}}$$

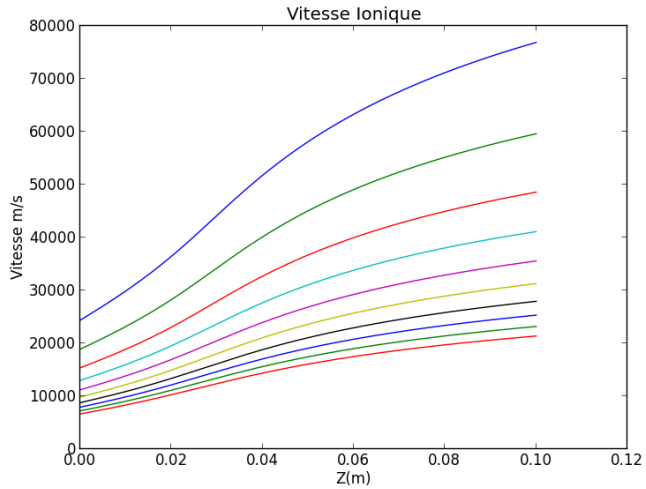
$$Thruster\ efficiency = \frac{T^2}{2\dot{m}P}$$

ECR Thruster : Modeling

- Cyclotron resonance damping
- 1D magnetic nozzle
- Electromagnetic wave propagation in magneto-plasma



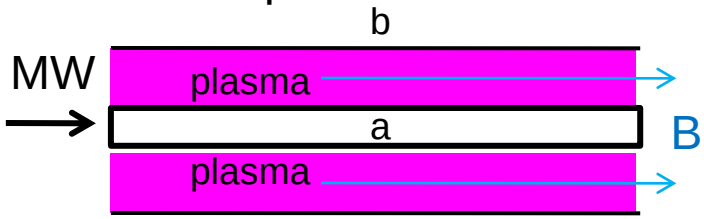
Electron Cyclotron Motion



Magnetic nozzle acceleration

Dielectric in magnetic plasma

When the space between the concentric conductors is filled with a uniform magnetized plasma, the permittivity ε of propagation medium becomes an anisotropic tensor. This one depends on the electron motion in presence of Lorentz force.



$$m\frac{d\vec{v}}{dt} = q(\vec{E}e^{j\omega t} + \vec{v}\times\vec{B})$$

$$v_x = \frac{e}{m}\frac{j\omega E_x - \omega_B E_y}{(\omega^2 - \omega_B^2)}$$

$$v_y = \frac{e}{m}\frac{j\omega E_y + \omega_B E_x}{(\omega^2 - \omega_B^2)}$$

$$v_z = -\frac{eE_z}{j\omega m}$$

With the constitutive relation of electromagnetic waves

$$j\omega\vec{D} = j\omega\varepsilon_0\vec{E} + j\omega\vec{P} = j\omega\varepsilon_0\vec{E} + \vec{J} = j\omega\varepsilon_0\vec{E} - Ne\vec{v} = j\omega\varepsilon_0\varepsilon_r\vec{E}$$

Dielectric tensor of magneto-plasma

$$\bar{\bar{\varepsilon}}_r = \begin{pmatrix} 1-\frac{\omega_{pe}^2}{\omega^2-\omega_B^2} & -j\left(\frac{\omega_B\omega_{pe}^2}{\omega(\omega^2-\omega_B^2)}\right) & 0 \\ j\left(\frac{\omega_B\omega_{pe}^2}{\omega(\omega^2-\omega_B^2)}\right) & 1-\frac{\omega_{pe}^2}{\omega^2-\omega_B^2} & 0 \\ 0 & 0 & 1-\frac{\omega_{pe}^2}{\omega^2} \end{pmatrix}$$

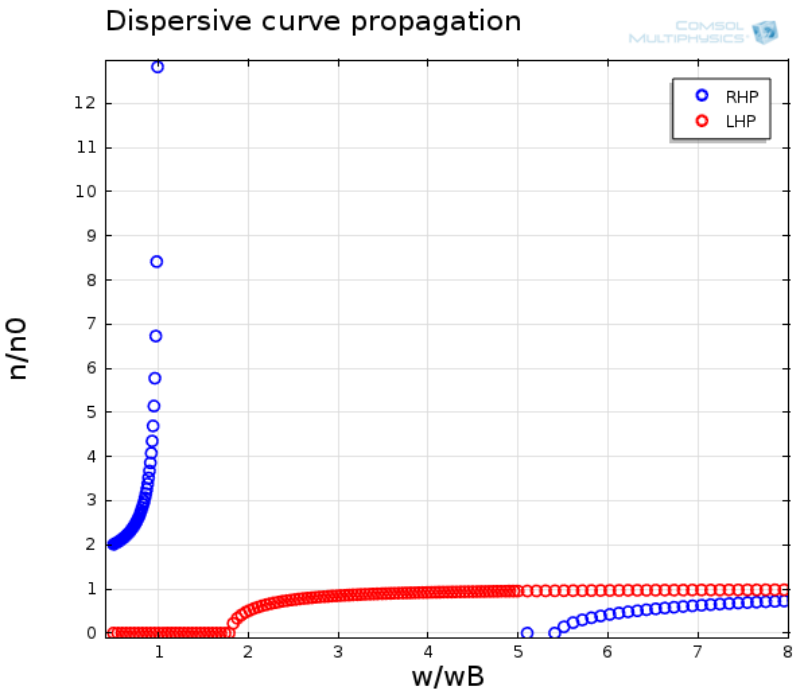
Existence of different mode of propagation

Dimensionless Mode analysis

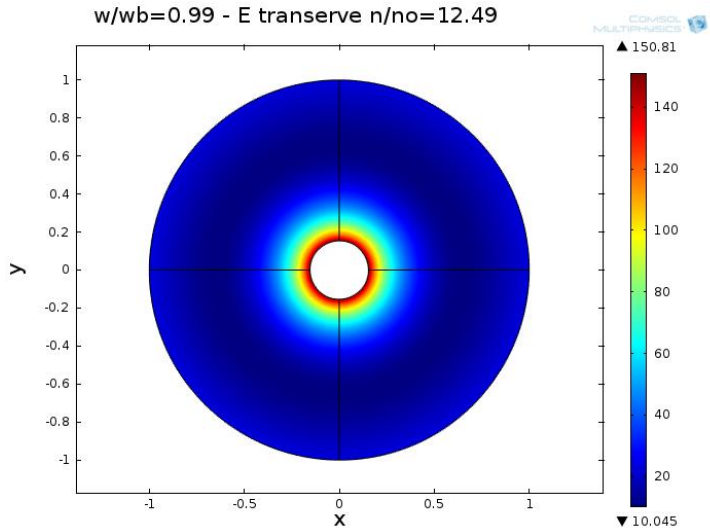
COMSOL MULTIPHYSICS®

Dispersion relation

$$\vec{k} \times \left(\vec{k} \times \vec{E}\right) + k_0^2 \varepsilon_r \vec{E} = 0$$

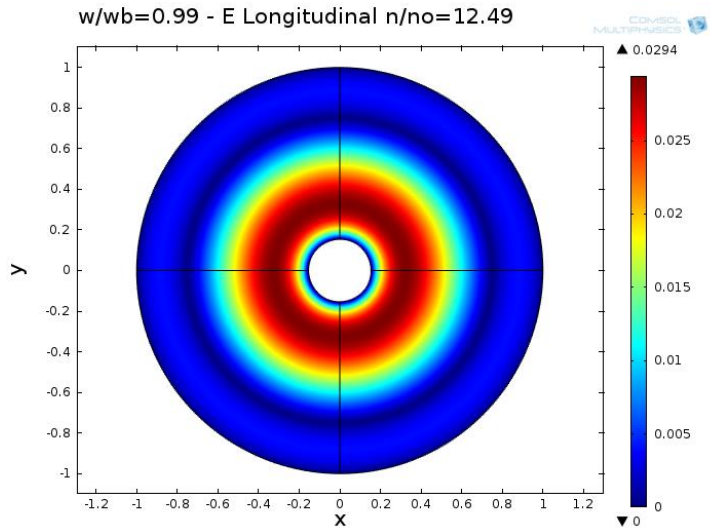


Transverse E field



Longitudinal E field

→ Quasi TEM Mode



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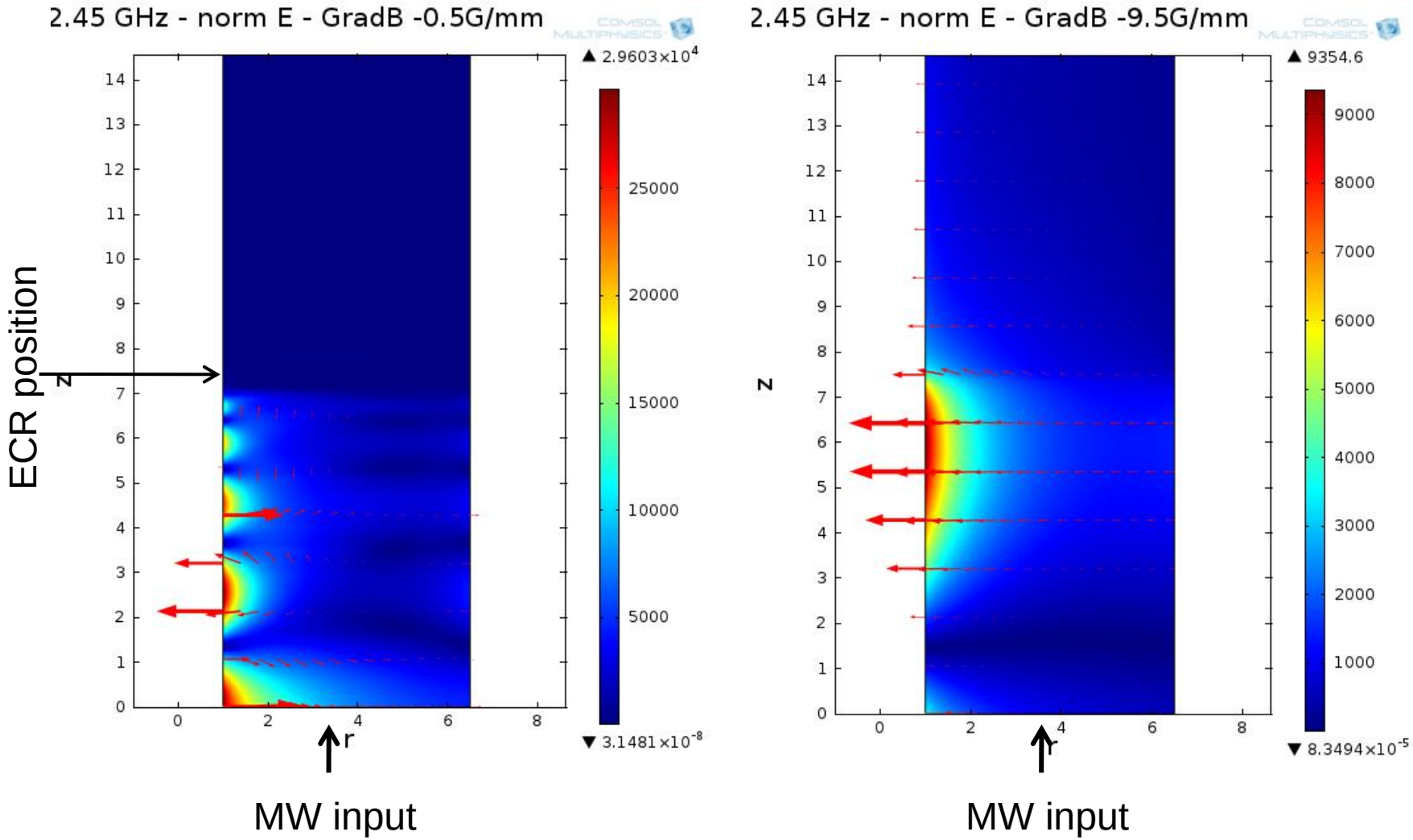
2D axisymetric simulation

Frequency Domain – magnetic Field decreasing



Future Works

❖ Experimental

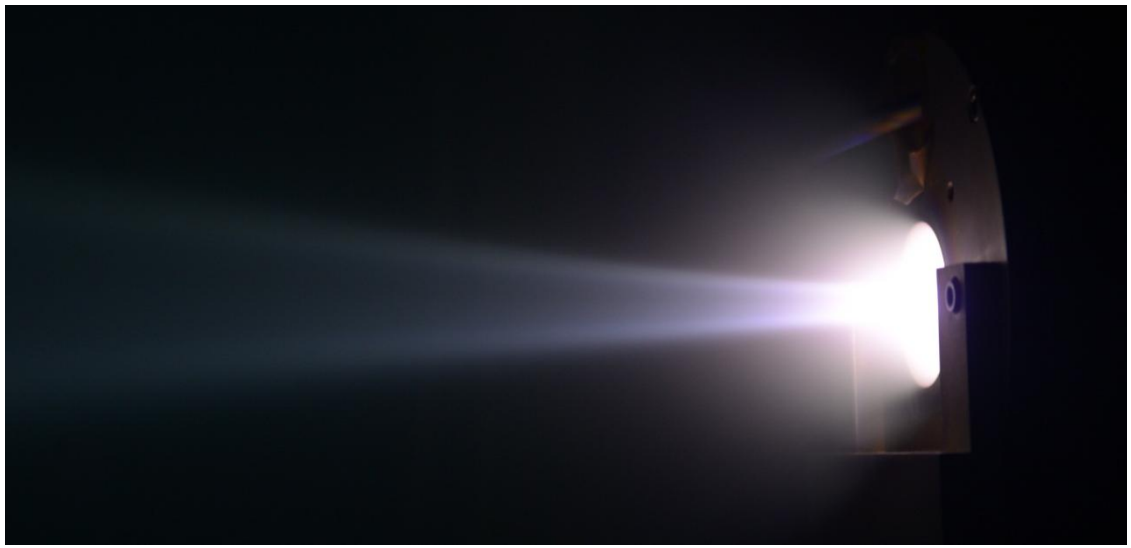
- New Design of ECR thruster
- New Diagnostics development (Hairpin Probes, interferometer, Tomography LIF).

❖ Modeling

- Simulation Electromagnetic waves propagation in no-uniform plasma density (sheath)

➢ Coupling a Electromagnetic wave simulation with a magnetic nozzle

Electromagnetic Wave Propagation in a Coaxial ECR Thruster



Thank you for your attention