EVROPSKÁ UNIE
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Operační program Výzkum, vývoj a vzdělávání

PlasmaLab@CTU

Resonance cavity as an education tool in PlasmaLab@CTU

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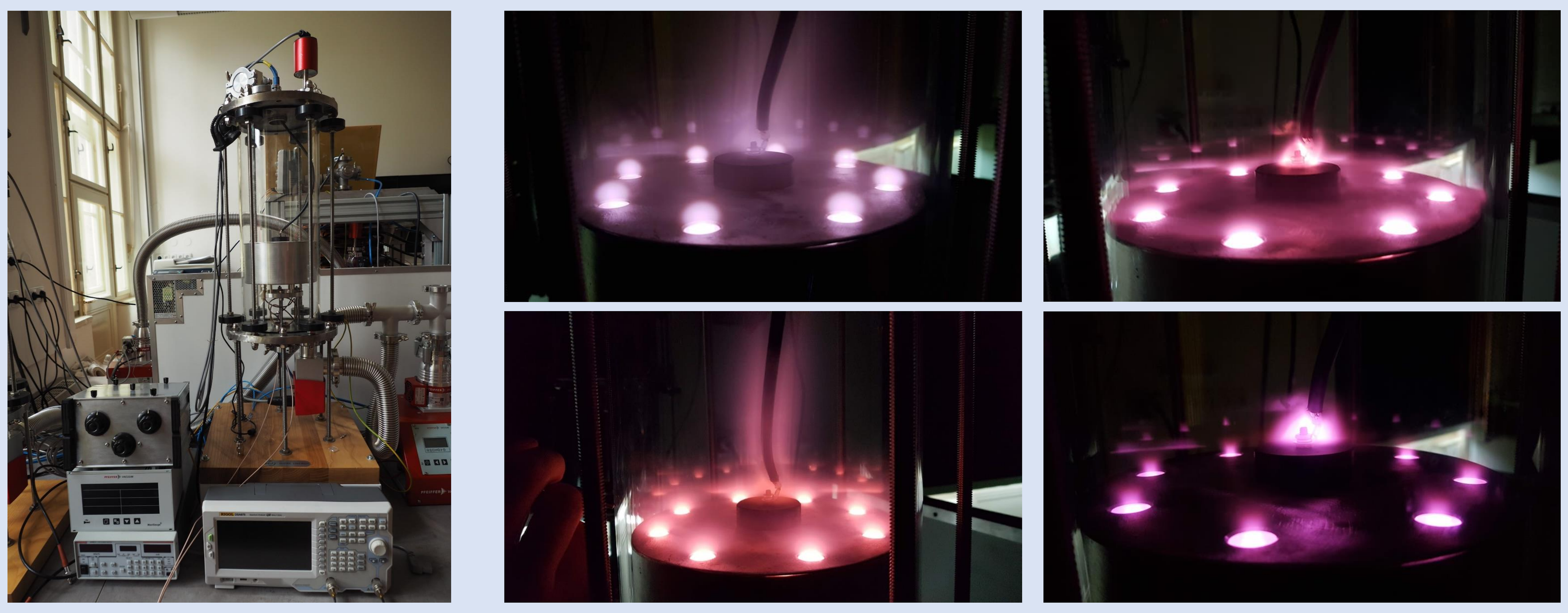
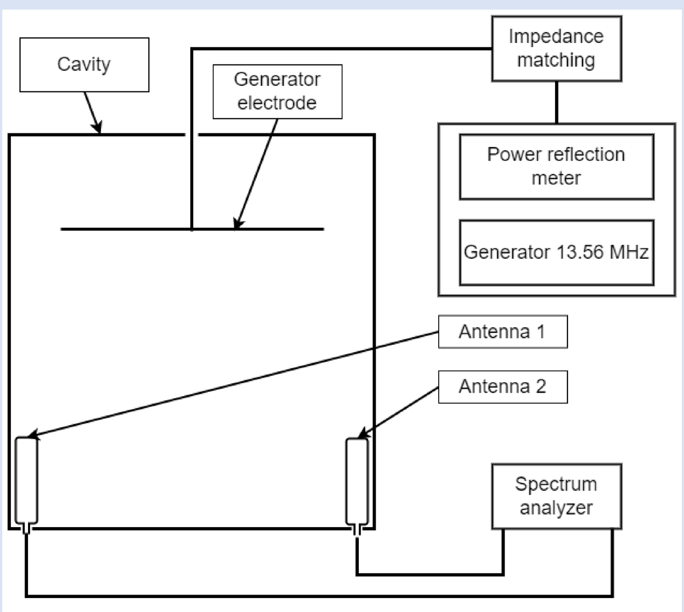
Resonance cavity experiment



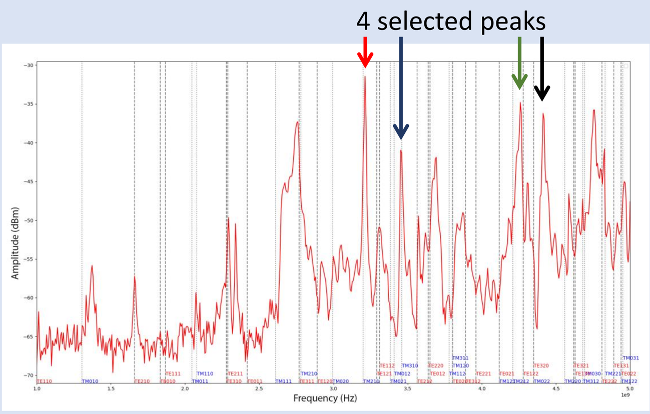
- Study of microwave resonator: estimation of resonance spectra
- Study of plasma – microwaves interaction: density estimation from the cavity resonance
- Fusion Relevance: Microwaves (ECRH) are a key heating tool for fusion plasmas



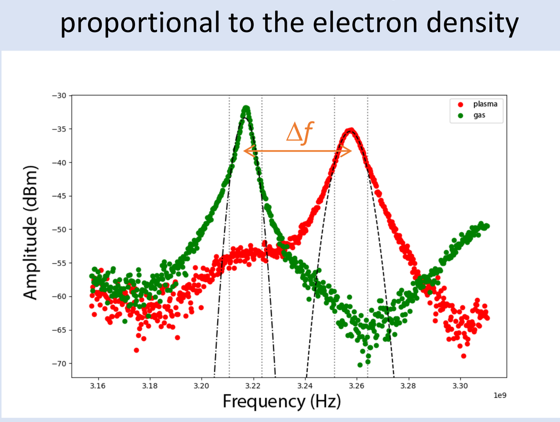
Parameters:
- **Cavity**
  - Stainless steel, cylindrical
  - R = 88 mm, L = 95 mm, (L = 70 mm)
- **Antennas**
  - 2 loop antennas ~ 1 cm diameter
  - Bottom lid, measure azimuthal magnetic field
- **Source**
  - Plasma generation, up to 70 W
- **Gases**
  - Ar, He, Ne, N_2, air
- **Pressure**
  - ~ 1 Pa – ~ 600 Pa, depends on gas

Initial results

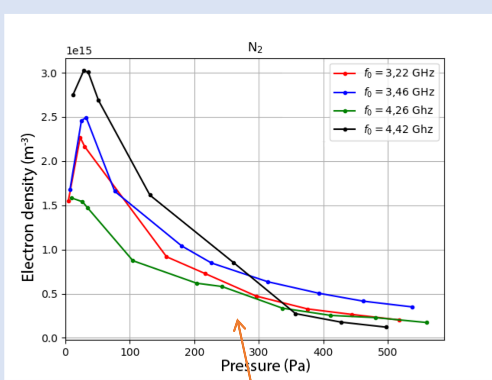
Spectrum with original antennas



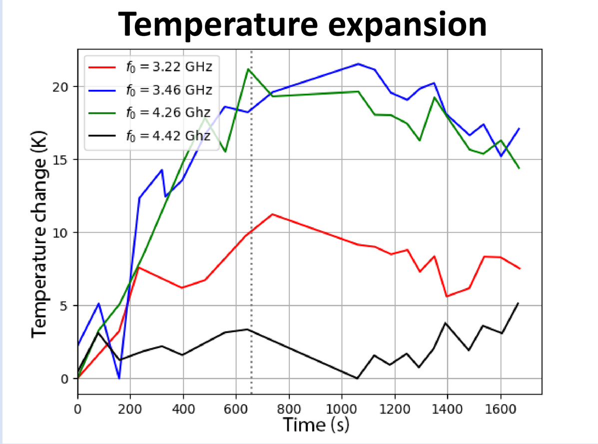
Measurement method
Shift of the resonance peak is proportional to the electron density



Electron density as a function of pressure for nitrogen



Temperature expansion



Temperature expansion of the cavity
- Plasma was generated 11 times for 30 s by power 70 W
- After that, the frequency was measured for another 15 minutes
- Temperature raised by ~ 20 degrees

$$\Delta T = \frac{1}{\alpha}\frac{f(T_0) - f(T_0 + \Delta T)}{f(T_0 + \Delta T)}$$

Green and blue lines consistent
Red and black not consistent – are they resonance peaks at all?

Theory

Resonant frequencies in cylindrical cavity with a diameter R and length L

- p_{mn} is the *m*-th node of the *n*-th order of Bessel function $J_n(x)$
- p'_{mn} is the *m*-th node of the derivative of the *n*-th Bessel function $J_n(x)$
- *c* is the light speed, μ_r and ϵ_r is the relative permeability and permittivity

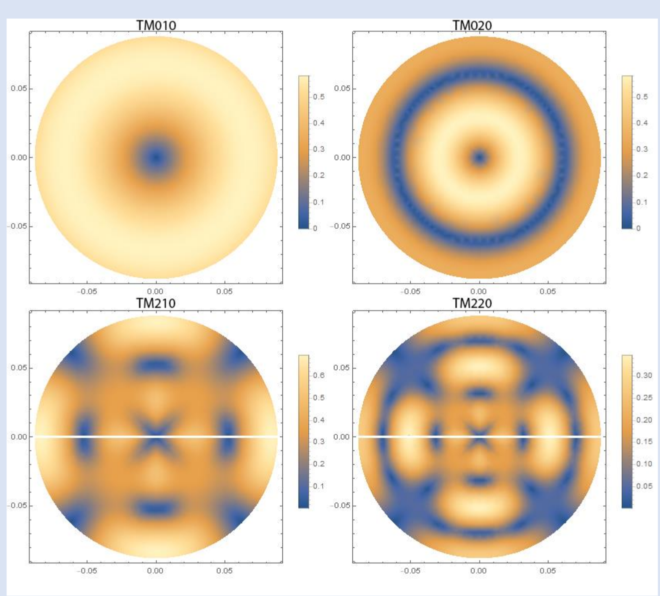
TM modes

$$f_{nml} = \frac{c}{2\pi\sqrt{\mu_r\epsilon_r}}\sqrt{\left(\frac{p_{nm}}{R}\right)^2 + \left(\frac{l\pi}{L}\right)^2}$$

TE modes

$$f_{nml} = \frac{c}{2\pi\sqrt{\mu_r\epsilon_r}}\sqrt{\left(\frac{p'_{nm}}{R}\right)^2 + \left(\frac{l\pi}{L}\right)^2}$$

Resonant modes



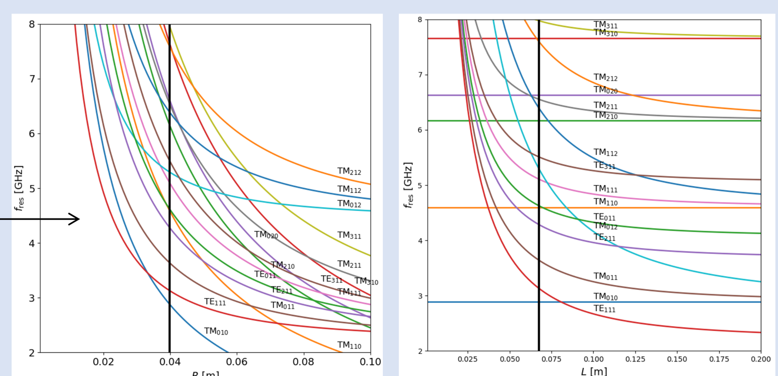
f_TMmn0 [GHz]

n\m	0	1	2	3
1	1,30	2,08	2,78	3,46
2	2,99	3,80	4,56	5,29
3	4,69	5,52	6,30	7,06

f_TEmn0 [GHz]

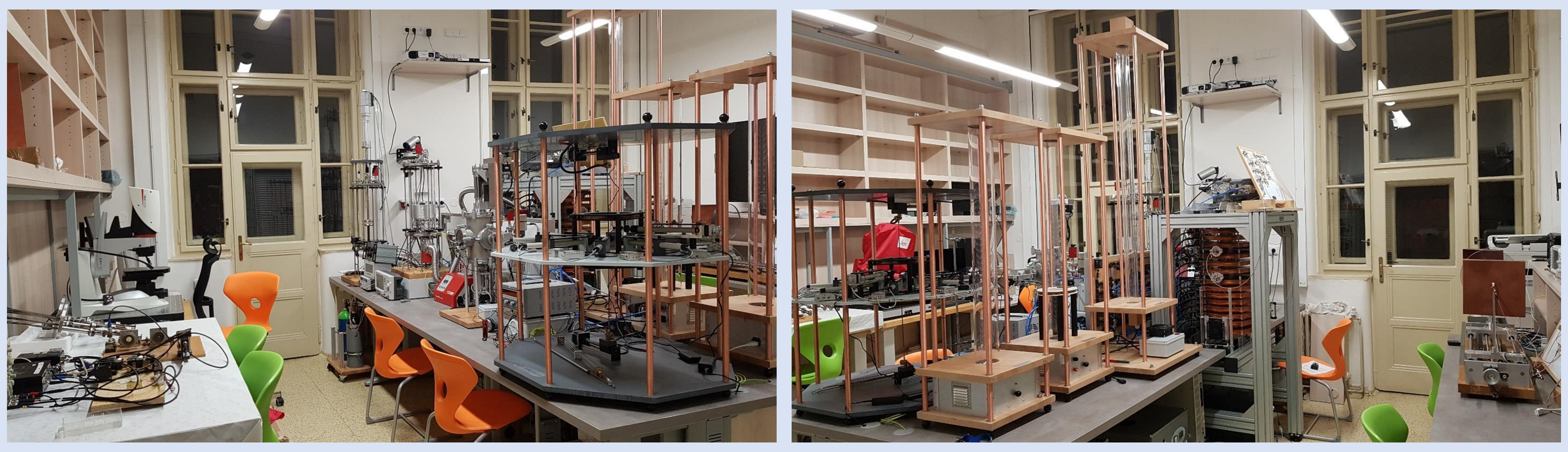
n\m	0	1	2	3
1	1,83	1,00	1,66	2,28
2	3,80	2,89	3,64	4,35
3	5,52	4,63	5,41	6,15

Resonant frequencies for variables *R* and *L*



PlasmaLab@CTU

- **High temperature plasma and fusion technology laboratory**
- **CTU has fusion programmes for Bc, MSc, PhD for past 10 years**
- **The lab was designed for PhD programme Double degree with Ghent University**
- **Serves for all other levels – Bc, MSc…**
- **Designed and built in 2017 – 2022**
- **Remotely controlled**
  - **Workspace 1 – Plasma**
    - Linear magnetic trap
    - Paschen curve
    - Discharge tubes
    - Resonance cavity
  - **Workspace 2 – Magnetic and electric fields**
    - Magnetic stand
    - Electrostatic probes stand
    - Microwave interferometry
  - **Workspace 3 – Optics**
    - Laser spectroscopy
    - Sonoluminescence
    - 3D microscope
  - **Workspace 4 – GOLEM tokamak**
    - Established tokamak in CTU
    - Fully remotely controlled
    - See the poster of Sara Abbasi

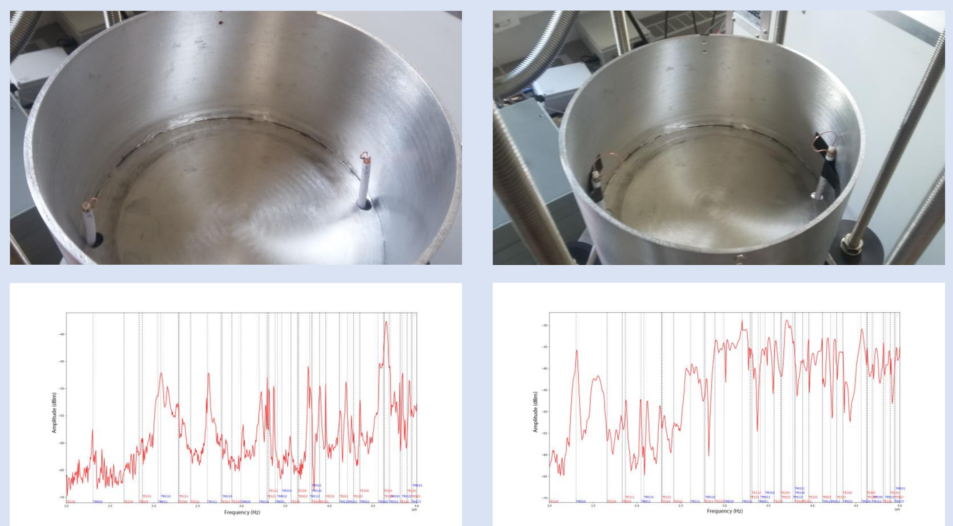


Antennas

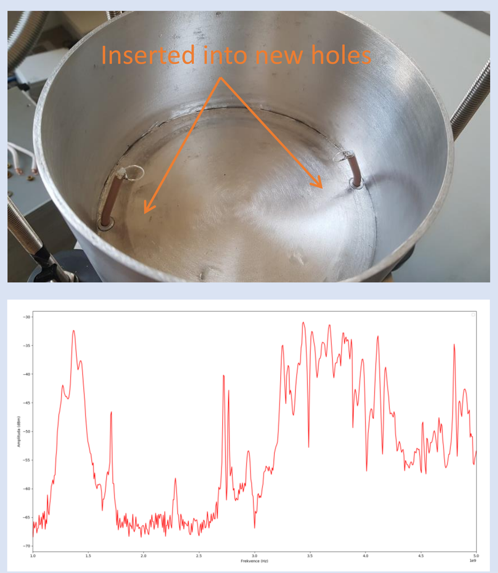
Original antennas

- Modes are not clear
- Discrepancy in predicted and measured modes
- TM_{010} mode (1.3 GHz) not consistent

Experiments with antennas
- Testing new antennas with different cross-section, orientation, position

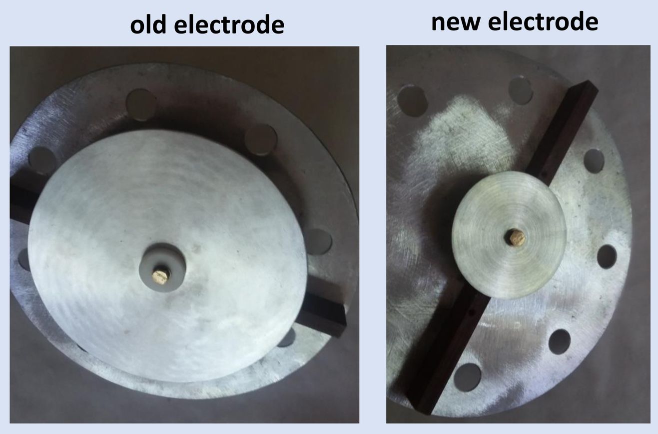


New sets of antennas
- Tuned for the TM_{010} mode (1.3 GHz)
- Need better impedance tuning



Electrodes

- Big electrode disturbs the resonator, mainly TM modes
  - Effectively reduces the *L* from 95 mm to 70 mm
- Smaller electrode – more homogeneous plasma



Conclusions/ questions to be addressed

- **Achievements**
  - Great educational tool for teaching
  - Bc thesis defended, used in experimental classes for Bc and MSc students
  - Measured electron density profiles in 4 gases: Ar, He, Ne, N_2
  - Set of antennas and the electrode for plasma generation upgraded
  - Great potential for detailed studies of resonators, practice with antennas, plasma propagation
- **Future outlook**
  - Improvement of the practice with antennas – set for manufacturing antennas and fine tuning of impedance (stub)
  - Improvement of the quality of the resonator – inner high-conductivity layer
  - Match a model of plasma propagation inside the resonator
  - Better pressure control for low pressures

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