Recombination of H_3^+ ions with electrons in ambient neon gas

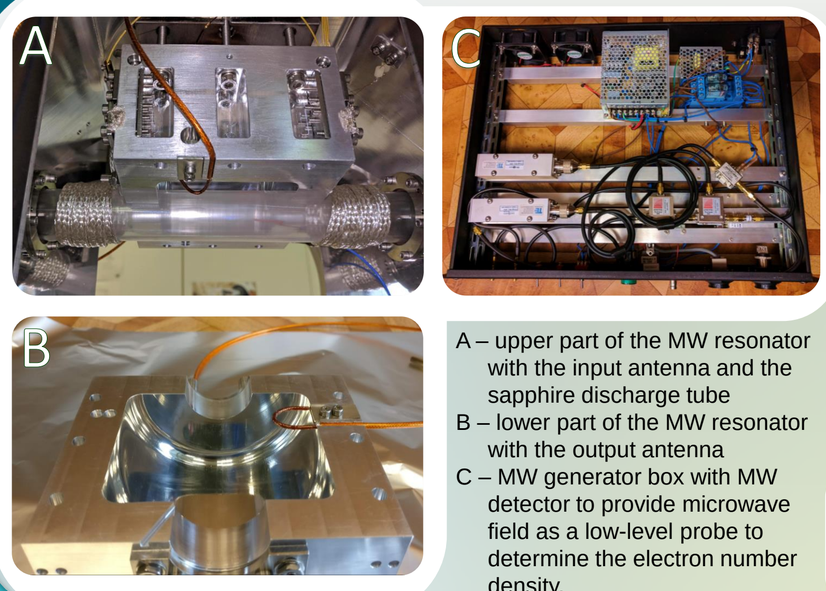
Shapko D., Dohnal P., Uvarova L., Kassayová M., Roučka Š., Plašil R., Glosík J.

Department of Surface and Plasma Science, Faculty of Mathematics and Physics,
Charles University, Prague, Czech Republic.

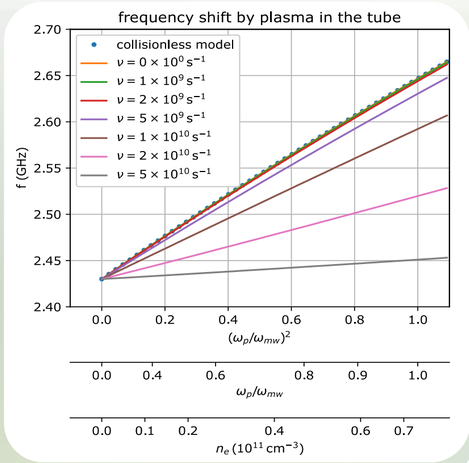
Motivation

The Cryogenic Stationary Afterglow apparatus in conjunction with a continuous wave Cavity Ring-Down absorption Spectrometer (Cryo-SA-CRDS) is a highly sensitive experimental setup for precise study of electron-ion recombination in plasmas in the temperature range of 30-300 K.[1,2] With the purpose of doing accurate direct measurements of electron number density the microwave diagnostic [3,4] was newly implemented.[5] The results of the first calibrations are presented.

MW diagnostics

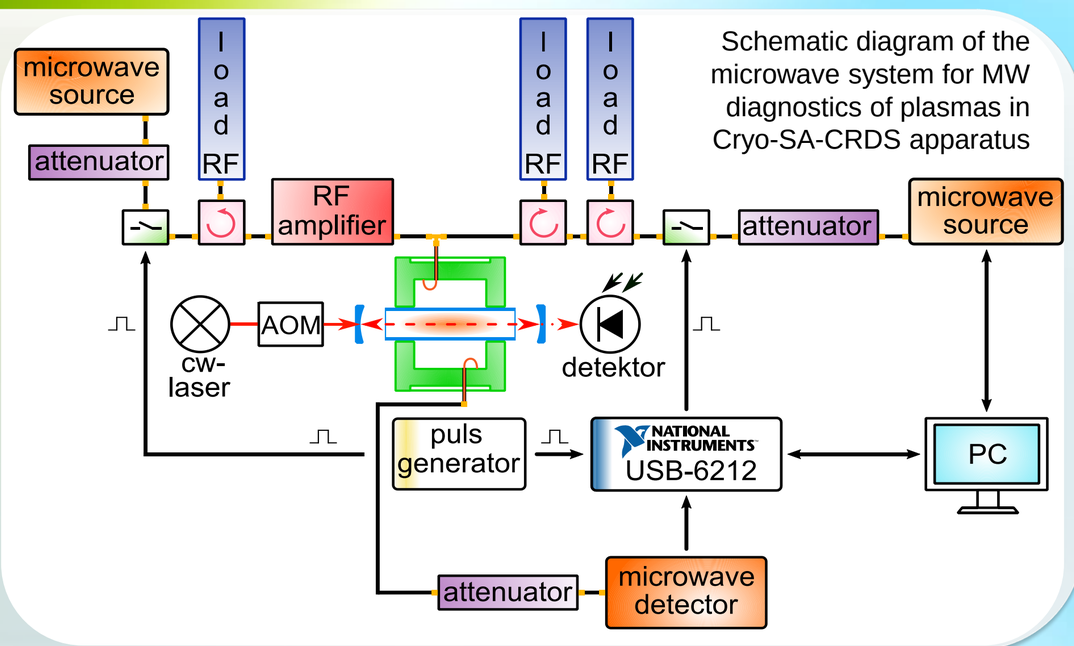


A – upper part of the MW resonator with the input antenna and the sapphire discharge tube
B – lower part of the MW resonator with the output antenna
C – MW generator box with MW detector to provide microwave field as a low-level probe to determine the electron number density.



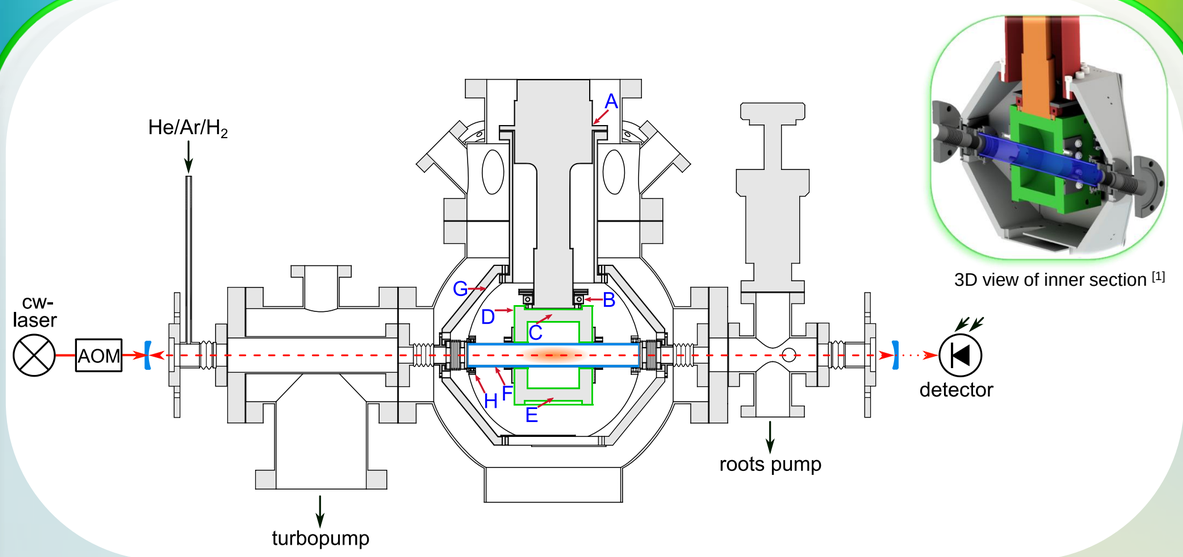
[4]

$$N_e(0) = \Delta f_r f_r \frac{2\pi m_e}{e_0^2} \frac{\int_v E^2 dv}{\int_{v'} I_0\left(\frac{2\cdot 405}{r_1} r\right) E^2 dv}$$



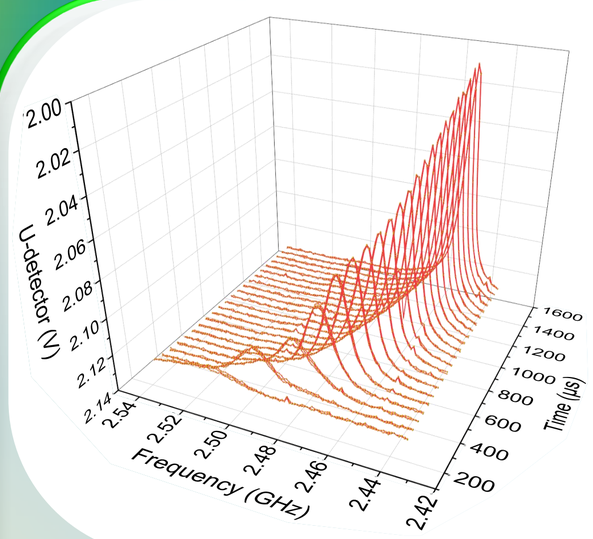
Schematic diagram of the microwave system for MW diagnostics of plasmas in Cryo-SA-CRDS apparatus

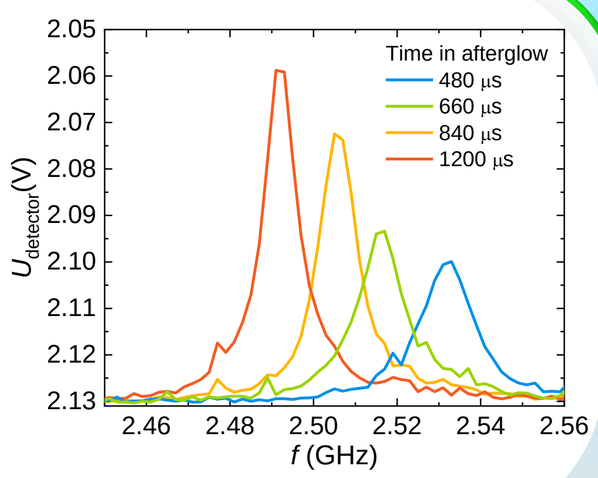
Experimental setup



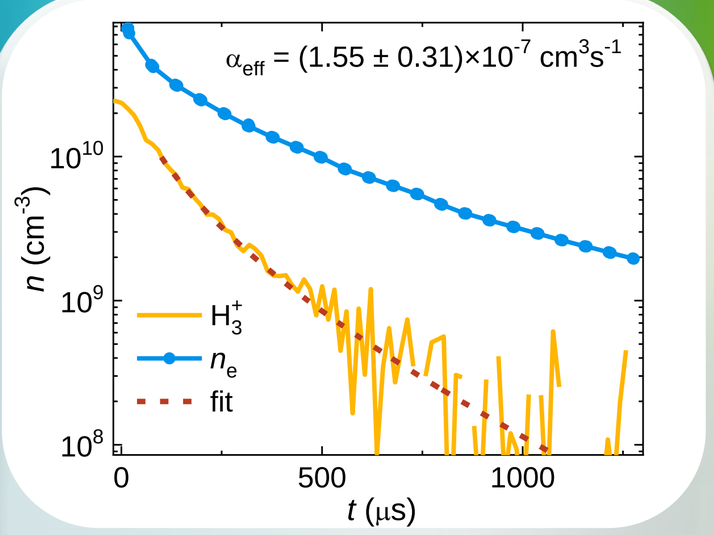
Schematic diagram [5] (not to scale) of the cryogenic stationary afterglow apparatus equipped with a near-infrared cavity-ring-down spectrometer (Cryo-SA-CRDS). A discharge is periodically ignited in the microwave resonator in the middle part of the sapphire discharge tube. Gas of the desired composition (e.g. He/Ar/H_2 or He/H_2) enters the tube on one side and it is continuously pumped out on the other side by roots pump. The laser light modulated by the acousto-optic modulator (AOM) is injected through the mirror on one side and photons exiting the cavity are detected by an InGaAs avalanche photodiode. The capital letters denote positions of various temperature sensors. The sapphire tube is 20 cm long, and its inner diameter is 2.5 cm. The discharge tube is cooled by Sumitomo RDK 408S cold head which second stage (orange) is attached to the upper part of the resonator (green). [1]

Resonance frequency

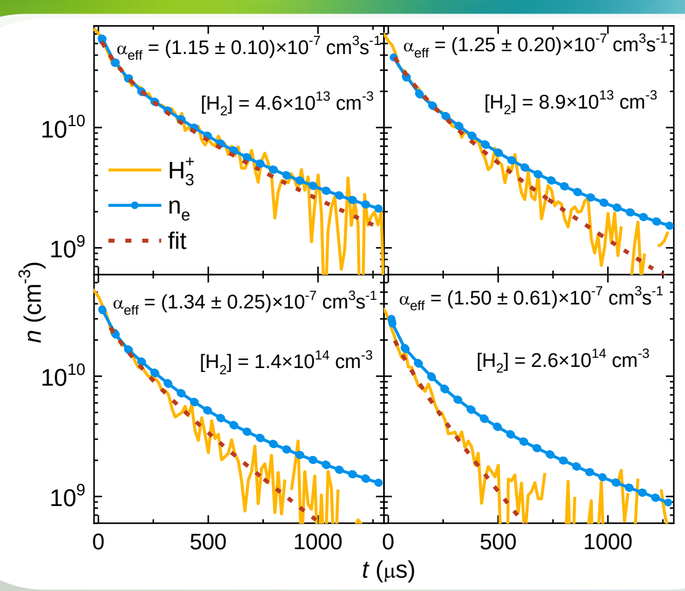




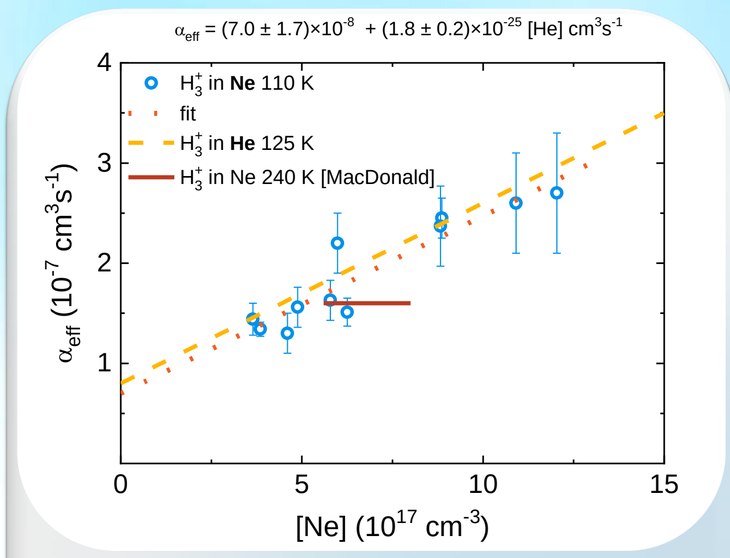
3D [5] and 2D graphs of the time evolution of the frequency response of cylindrical resonant cavity obtained in helium buffered plasma at T = 200 K, [He] = 3×10^{17} cm^{-3}, [Ar] = 2×10^{14} cm^{-3} and [H_2] = 4.6×10^{13} cm^{-3}. The frequency position of the center of each peak-like feature gives resonant frequency of the microwave resonator at a particular time in the afterglow and through equation[4] the electron number density.



Time evolutions of the number density of the H_3^+ ions and electrons (n_e) in the Ne buffered afterglow plasma T = 110 K, [**Ne**] = 6.3×10^{17} cm^{-3}, [Ar] = 5.4×10^{13} cm^{-3}, [H_2] = 1.0×10^{14} cm^{-3}. [5]



Time evolutions of the number density of the H_3^+ ions and electrons (n_e) in the He buffered afterglow plasma at different number densities of [H_2] from 4.6×10^{13} to 2.6×10^{14} cm^{-3}. T = 200 K, [**He**] = 3×10^{17} cm^{-3}, [Ar] = 2×10^{14} cm^{-3}. [5]



The dependence of the effective recombination rate coefficients for recombination of H_3^+ ions with electrons on buffer gas number density obtained in the present study in **Ne** buffer gas at 110 K. [5]

Conclusion

- The newly implemented microwave diagnostic allows us evaluate electrons number density in the sapphire discharge tube of Cryo-SA-CRDS using well known equation [4] for shift of resonance frequency of cylindrical resonator.
- The calibration measurement show that the measured time decay of the H_3^+ ions is in excellent agreement with the obtained time evolution of the electron number density at conditions where H_3^+ is the dominant ion in the afterglow.
- We suppose that the MW diagnostic will help us to study the recombination of ions with electrons even at conditions when they are not the dominant ionic specie in the afterglow plasma, like in case of H_3^+ ions in Ne buffered plasma.

References

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- [2] D. Shapko, P. Dohnal, M. Kassayová et al., J. Chem. Phys, 152, (**2020**) 024301(1-11).
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- [5] D. Shapko, P. Dohnal, Š. Roučka et al., J. Mol. Spectrosc., 378 (**2021**) 111450 (1-7)

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