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# Spectroscopic study of the neutral gas temperature of silicon based DC MHCD in various gases close to atmospheric pressure

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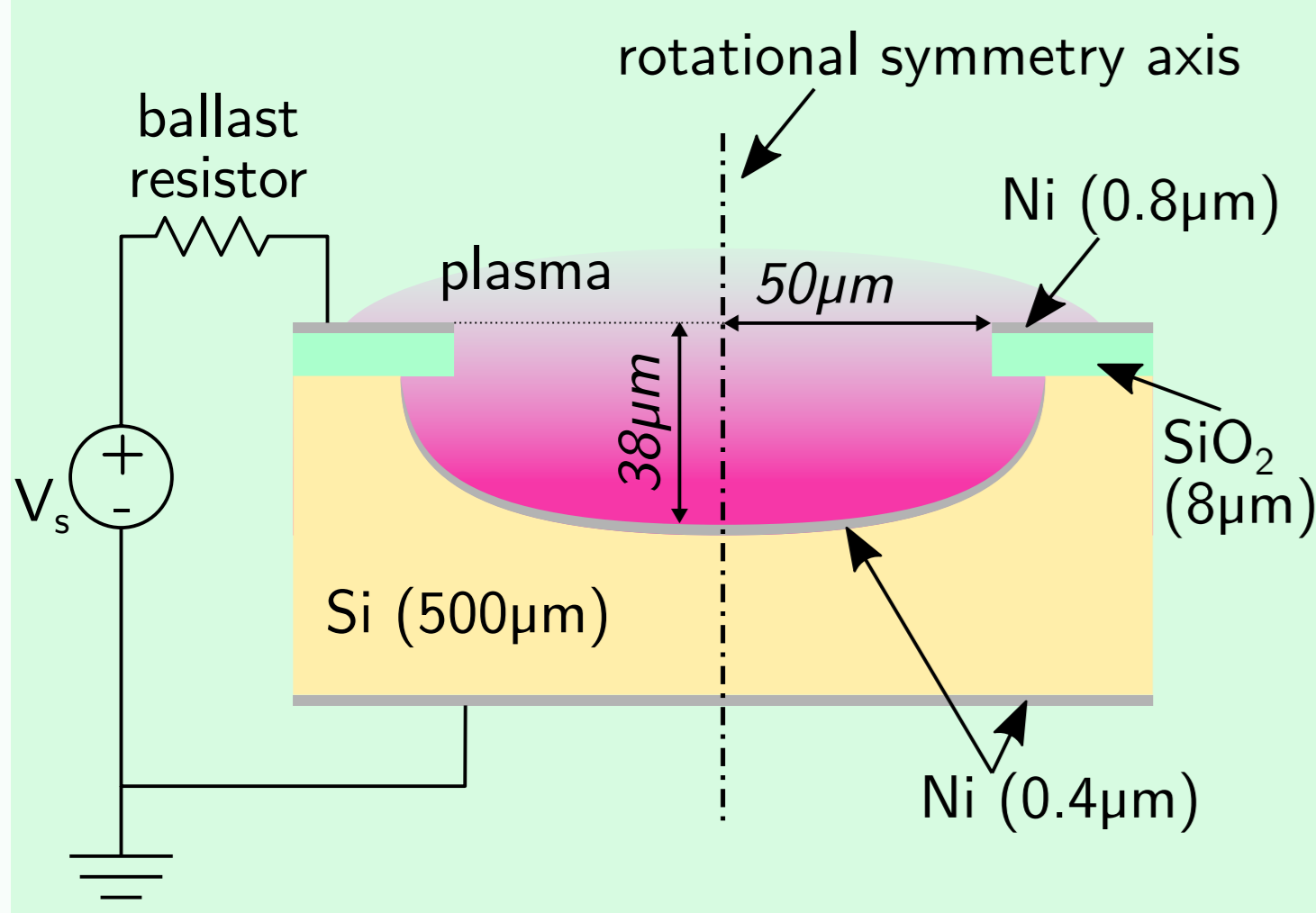
## Motivation

Micro hollow gas discharges (MHCD) have been on high interest to produce highly ionized gas while keeping the gas temperature close to room temperature. This study focuses on the accurate measurement of the gas temperature in and out the cavity, operated in different regimes, by means of space resolved optical emission spectroscopy. Two approaches are applied depending on the gas mixture (He, Ar, N<sub>2</sub>):

- analysis of the profile of resonant atomic lines taking in to account the Van der Waals broadening,
- analysis of the relative population distribution of ro-vibrational N<sub>2</sub>(C-B) bands.

Limitations of the latter approach will be discussed specifically. Heat transfer and temperature gradient will be discussed with regard to the geometry and the material properties of the present MHCD design.

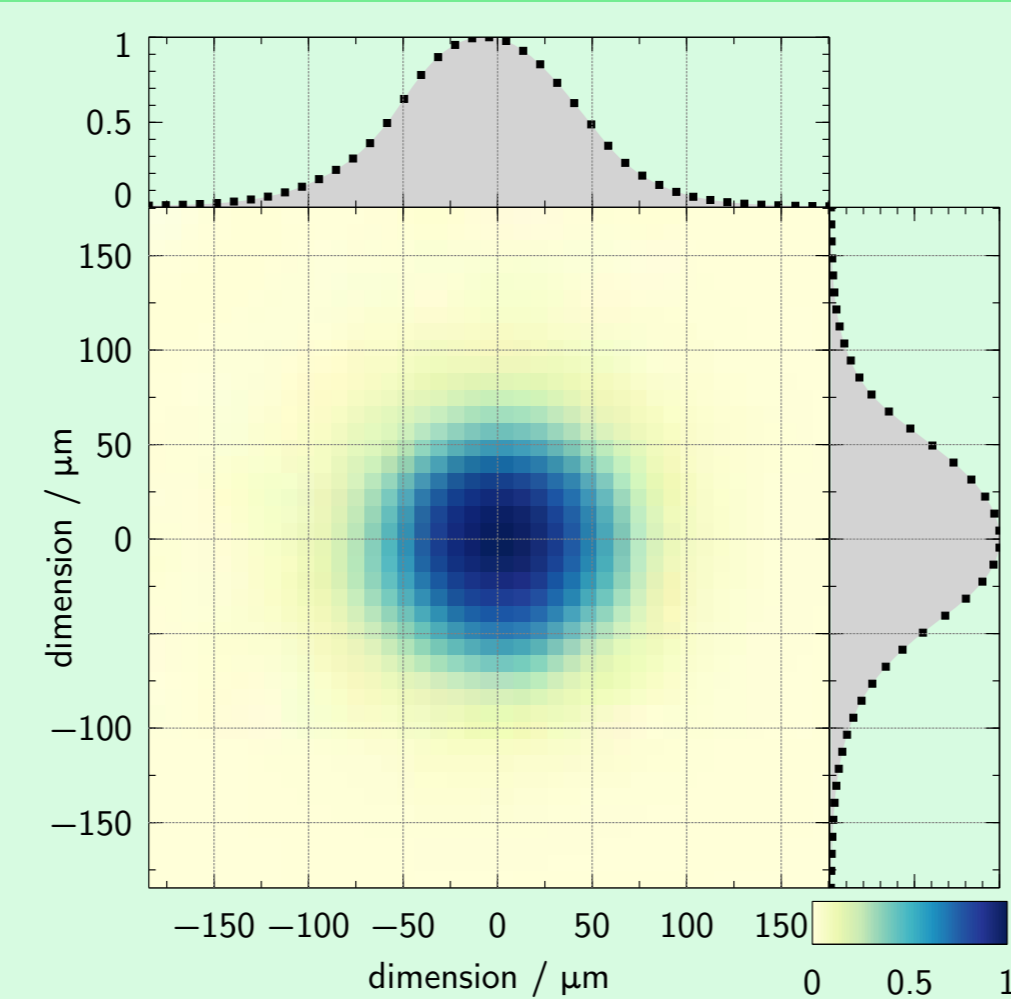
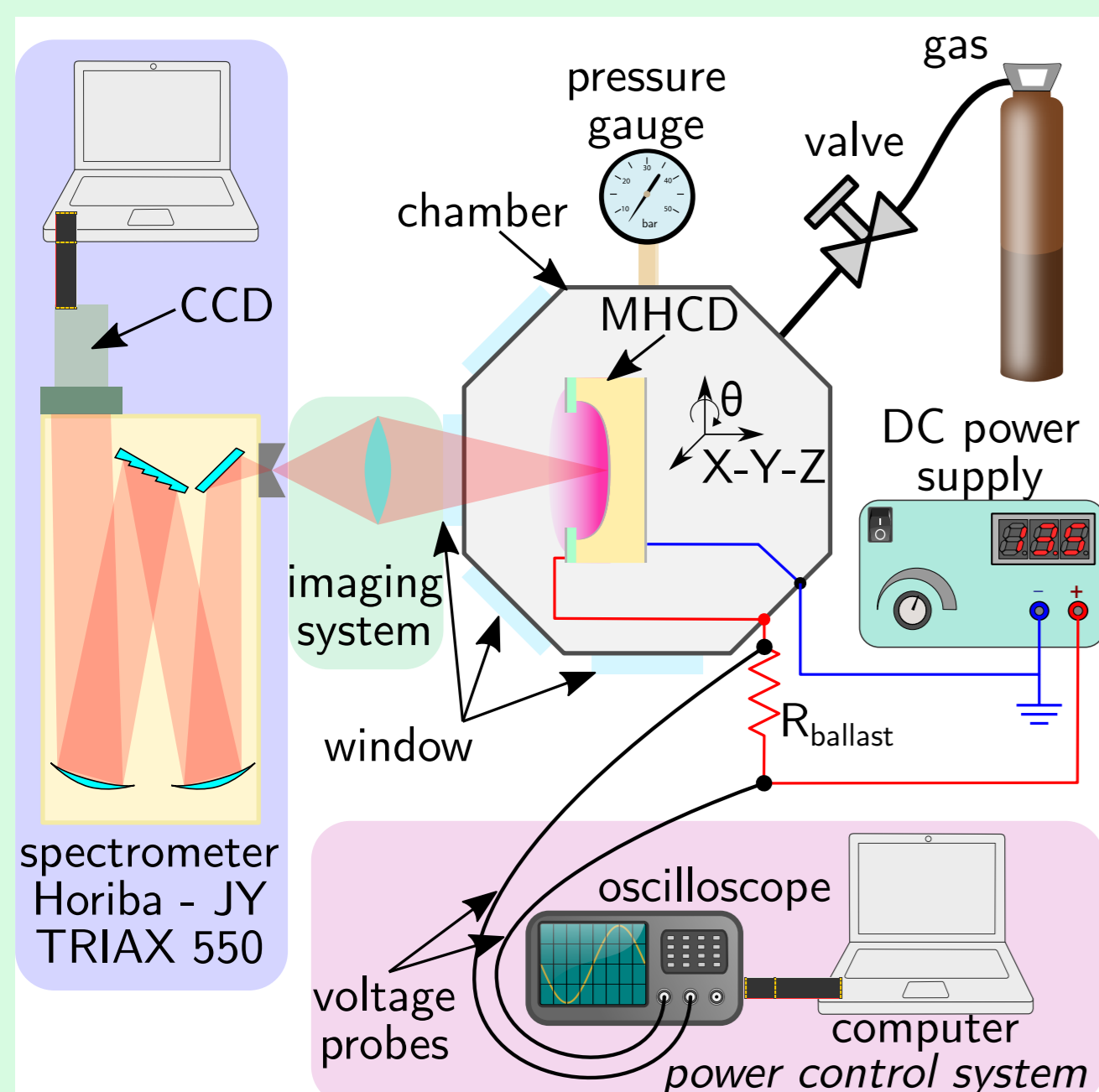
## Source plasma – micro-cavity plasma (MHCD)



Experimental conditions:

- Powered in DC,
- Polarity: positive ou negative,
- 0.2 µA à 600 µA,
- 2 mW à 150 mW.
- Gas pressure 0.26 atm à 1.2 atm,
- Gas: He / Ar / N<sub>2</sub>,
- MHCD arrays, e.g. 32 × 32 micro-cavities.

## Imaging optical emission spectroscopy



Front image of a single MHCD (100 µm diameter). Integration of the whole spectrum.

## Resonance broadening and rotational temperature of N<sub>2</sub>(C-B)

The pressure broadening contributes to the Lorentzian full width at half maximum (FWHM) of the line,  $w_L$ . At atmospheric pressure,  $w_L$  is dominated by the resonance broadening with a minor contribution due to the van der Waals interactions. Thus,  $w_L \approx w_R + w_{vdw}$ , with,

$$w_R = K(0, 1) \frac{r_e}{\pi} \sqrt{\frac{g_G}{g_R}} \lambda_0^2 \lambda_R f_R N, \quad (1)$$

$$w_{vdw} = 8.18 \cdot 10^{12} \lambda_0^2 (\bar{\alpha} \bar{R}^2)^{2/5} \left(\frac{T_g}{\mu}\right)^{3/10} \cdot N. \quad (2)$$

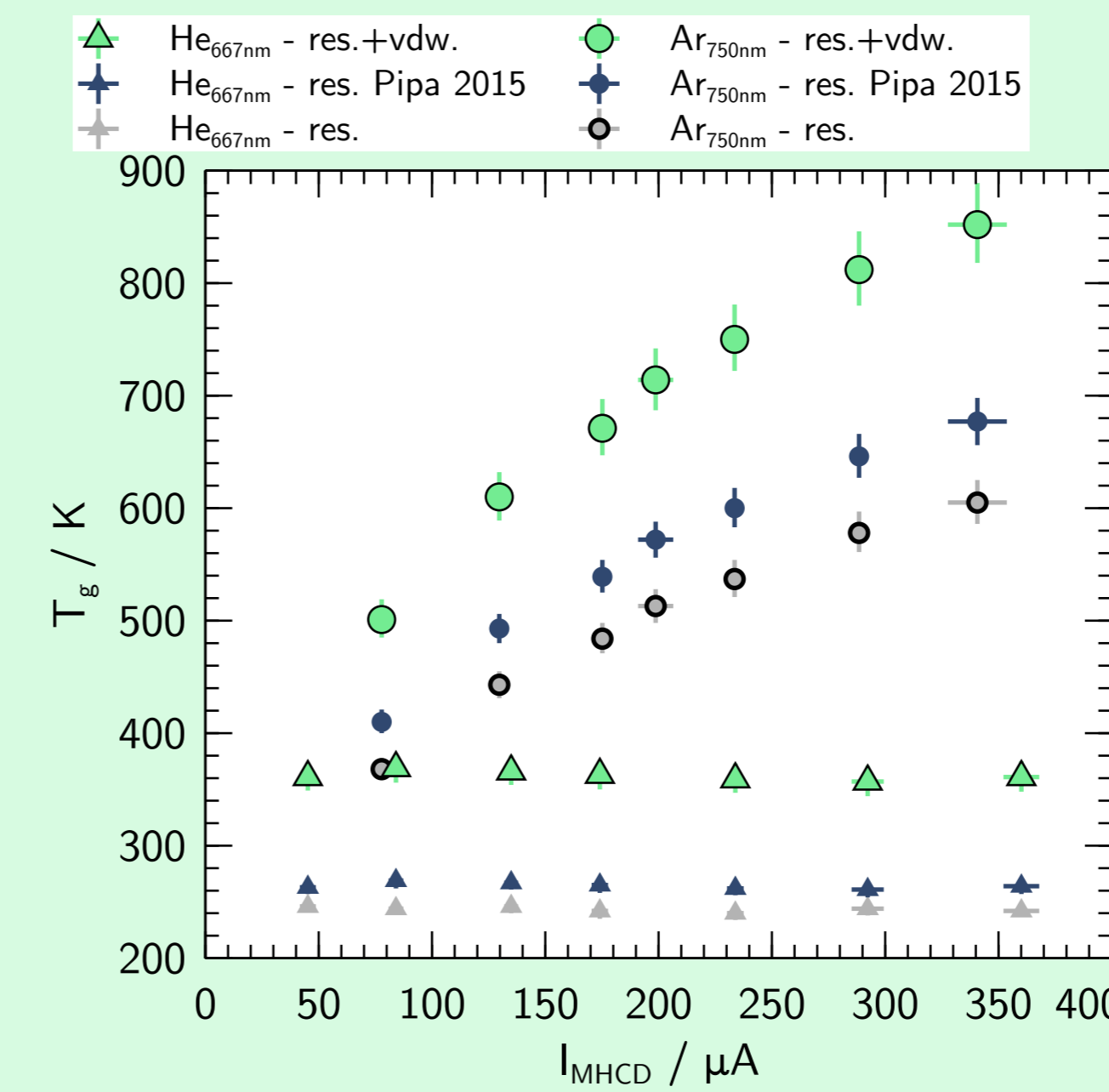
A detailed analysis of the line profile is used to determine  $T_g$ .

With reasonable assumptions,  $T_g$  is often considered to be equal to the rotational temperature ( $T_{rot}$ ) of diatomic molecules, e.g. N<sub>2</sub>. The relative spectral intensity ( $I_{J''}^{J'}$ ) of transitions from two different vibrational states ( $J' \rightarrow J''$ ) reads,

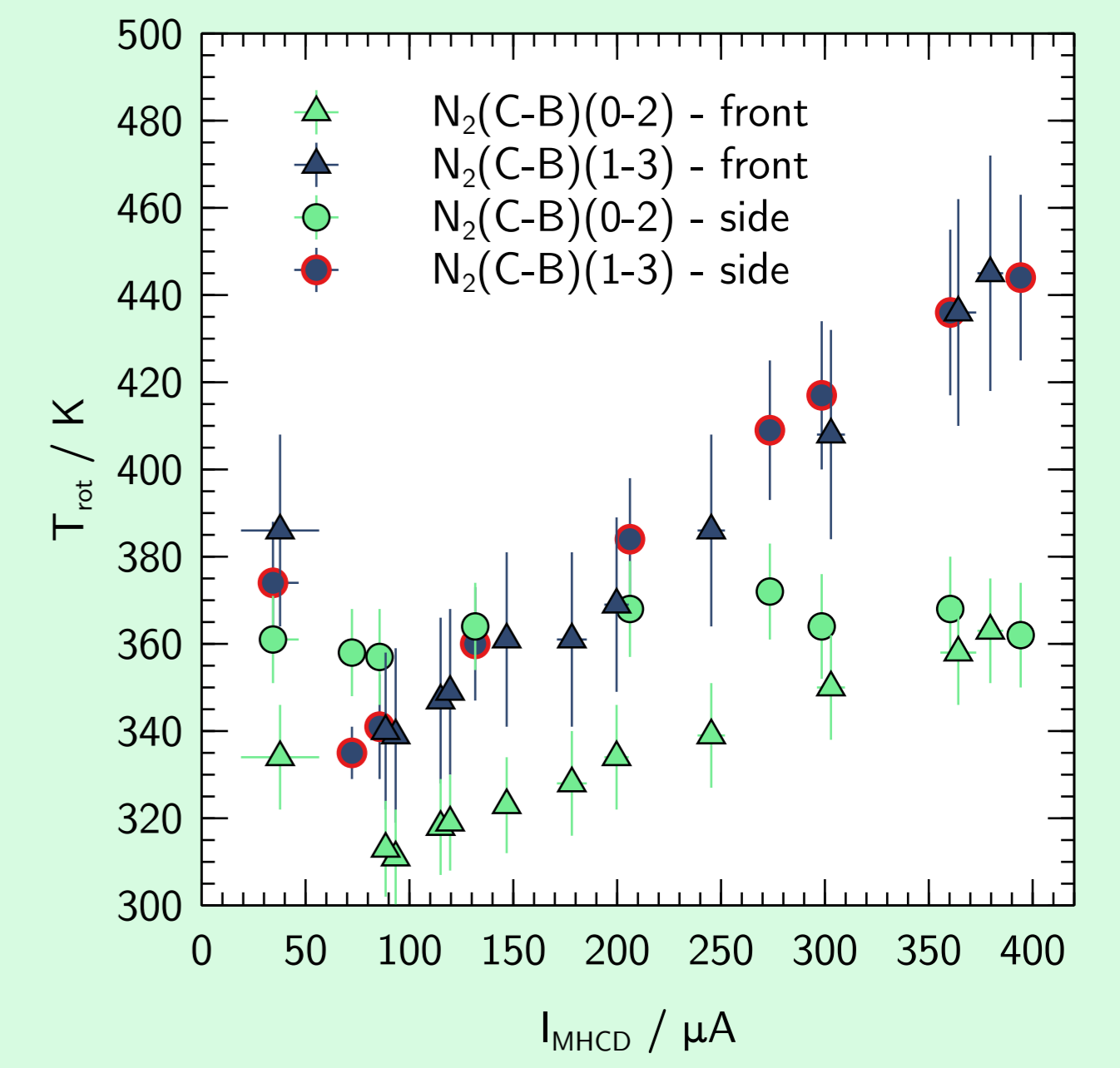
$$I_{J''}^{J'} \propto N_{v'} S_{J''}^{J'} \left(\nu_{v''}^{v'}\right)^4 \exp\left[-\frac{hc}{k_B T_{rot}} F_{v'}(J')\right]. \quad (3)$$

- Spectral simulation based on molecular constants of N<sub>2</sub>(C<sup>3</sup>Π<sub>u</sub>) determined for  $J \lesssim 25$ .
- Fitting routine using only four parameters and two optimization passes; computed confidence interval of 95 %, e.g. uncertainties.

## Temperatures inside/outside the MHCD – $T_g$ vs $T_{rot}$



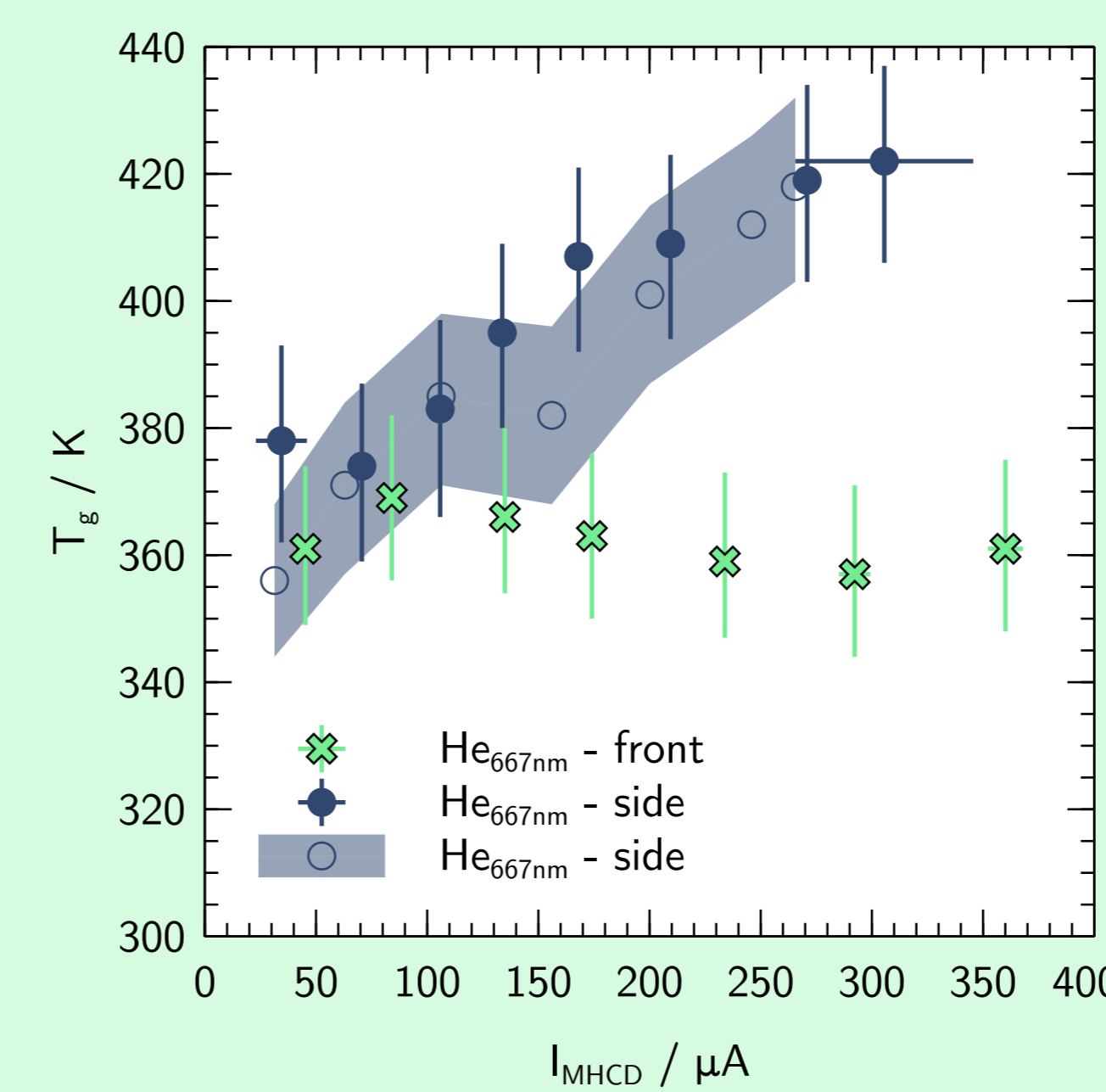
$T_g$  measured with line profile analysis. (0.66 atm).



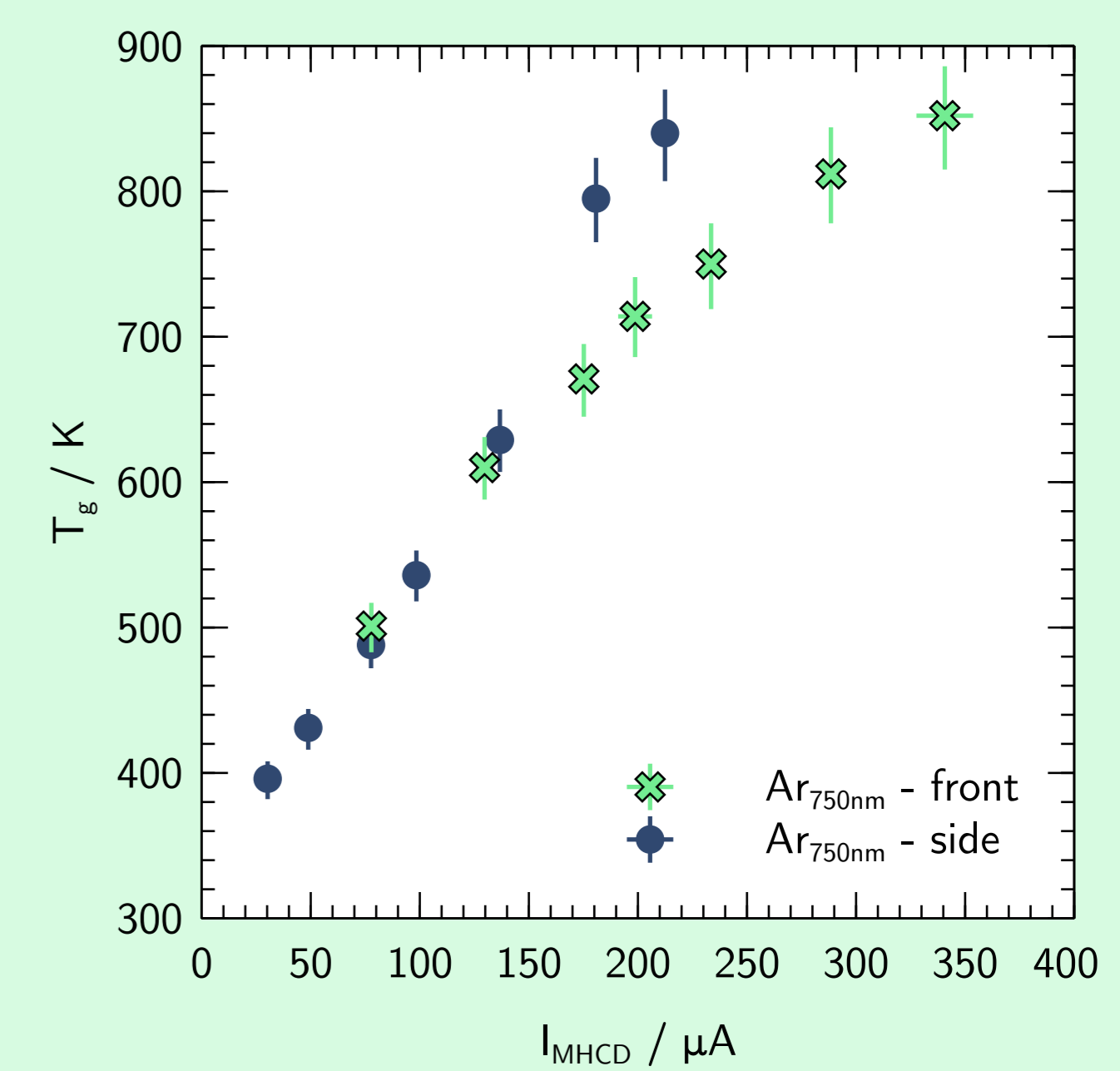
Temperatures inside/outside of the MHCD in He gas at 0.66 atm.

- Significant thermal differences between He and Ar,
- Discrepancies between  $T_g$  and  $T_{rot} \Rightarrow$  is N<sub>2</sub>(C-B) in equilibrium in He...?

## Focus on the temperature gradient...



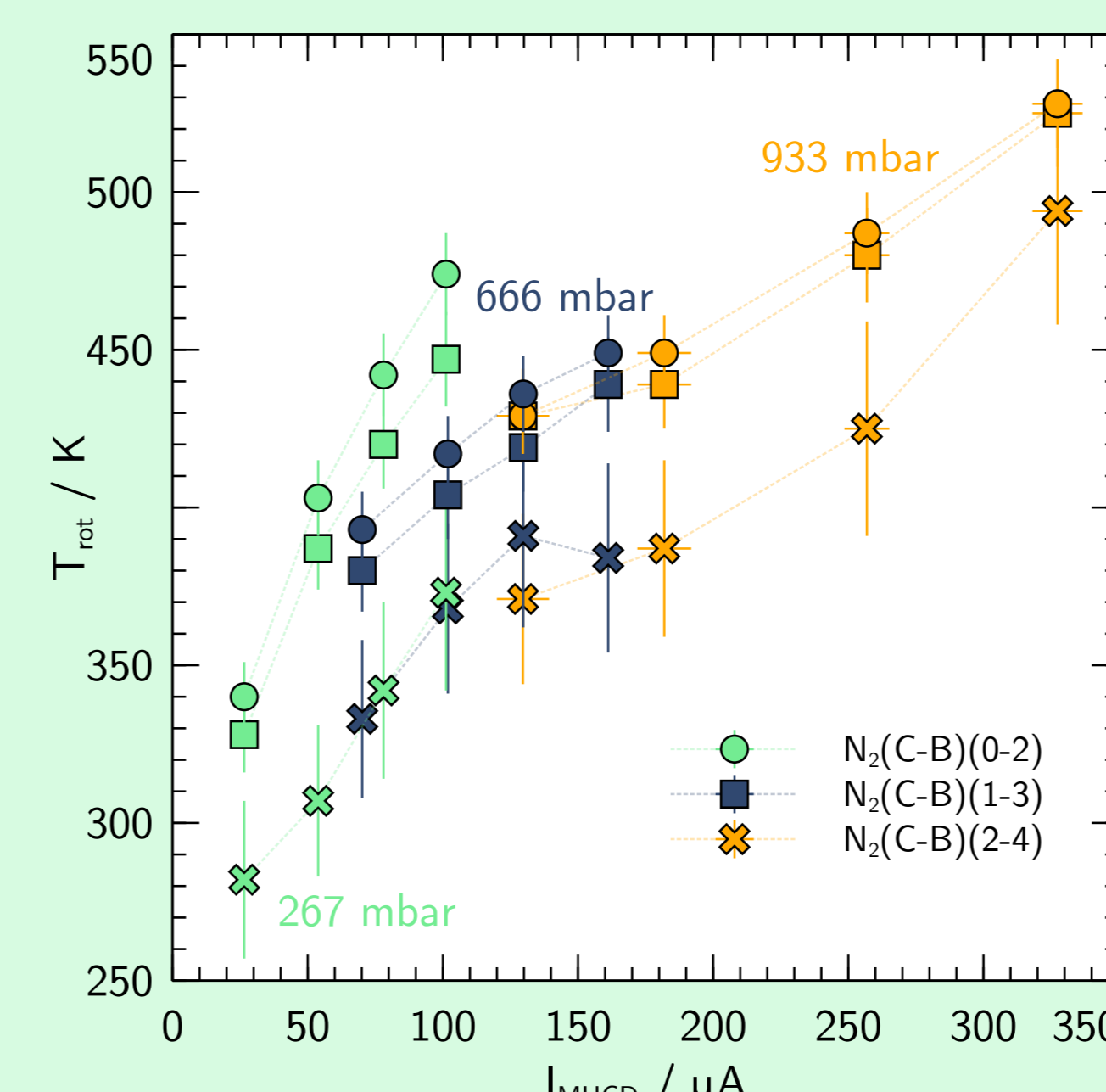
$T_g$  in He (0.66 atm).



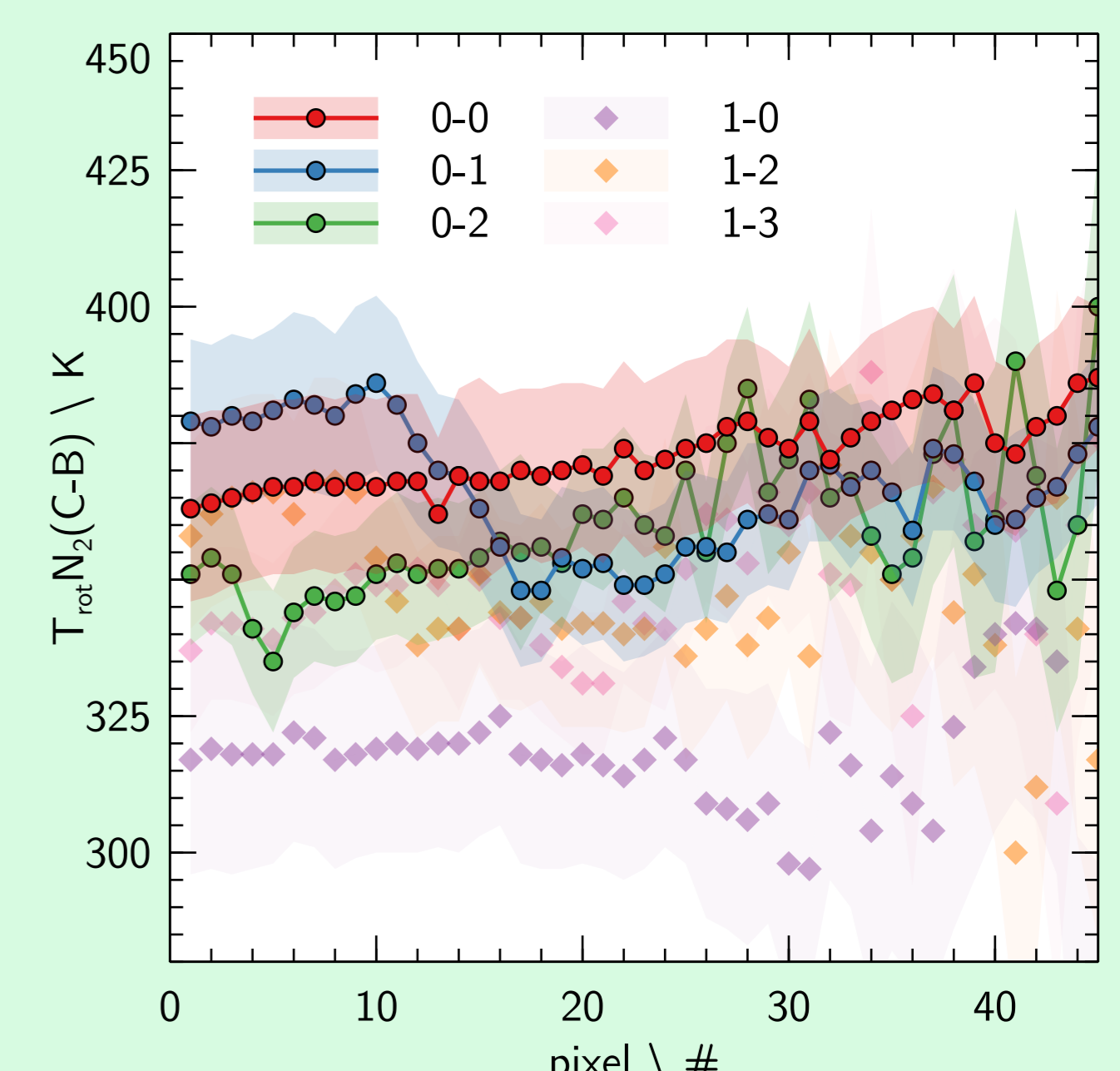
$T_g$  in Ar (0.66 atm).

- $T_g$  front corresponds to the light from the negative glow (the brightest ionized volume) above the cathode sheath,
- Si substrate acts as a heat sink while the SiO<sub>2</sub> plays the role of a thermal isolation with the anode surface.

## Comparison $T_{rot}$ N<sub>2</sub>(C-B) in MHCD and in guided ionization waves



$T_{rot}$  in pure N<sub>2</sub> MHCD.



$T_{rot}$  in He guided ionization waves at atmospheric pressure (APPJ).

- $T_{rot}$  in pure DC MHCD and in guided ionization waves...  $T_{rot} \approx T_g$ ?

## Concluding remarks

- Higher  $T_g$  and  $T_{rot}$  outside the cavity than inside  $\Rightarrow$  heat flux disturbed by SiO<sub>2</sub> layer,
- Closer to atmospheric pressure, is  $T_{rot}$  of N<sub>2</sub>(C-B) in equilibrium in He discharge...?
- Iseni S, et. al., 2019 On the validity of neutral gas temperature by emission spectroscopy in micro-discharges close to atmospheric pressure, PSST, 2019, in press.