Intérêt des transitions résonnantes en spectroscopie pour les plasmas froids atmosphériques:

diagnostic des ondes d'ionisations et de micro-cavités

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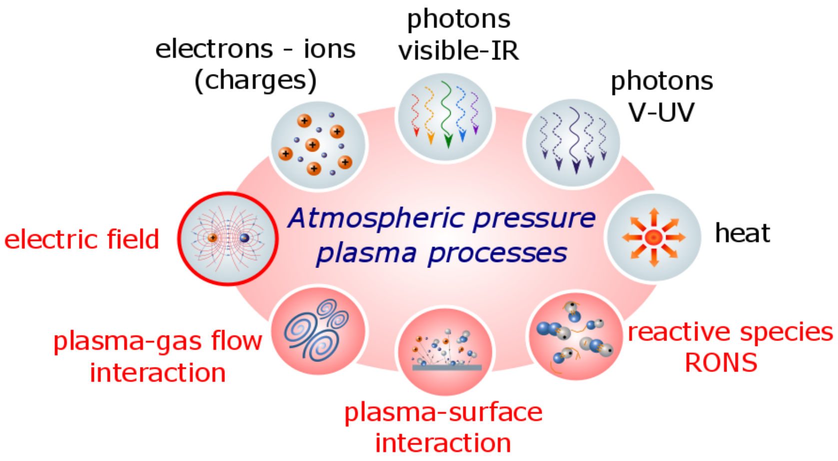
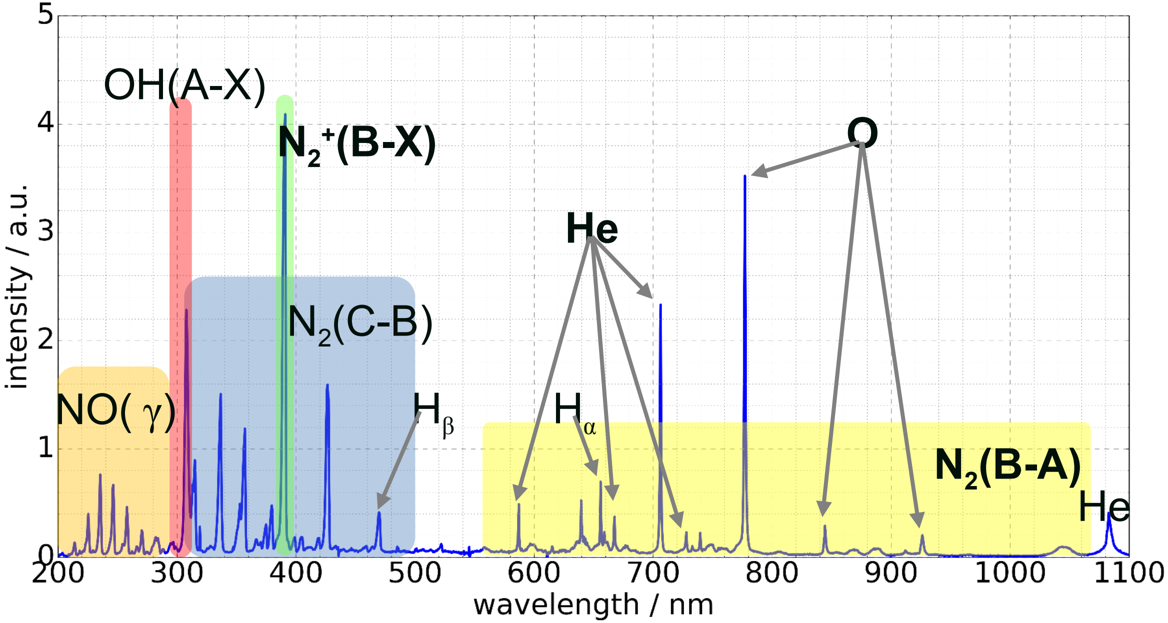
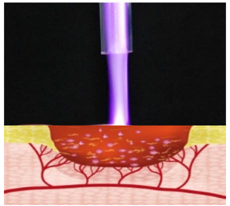
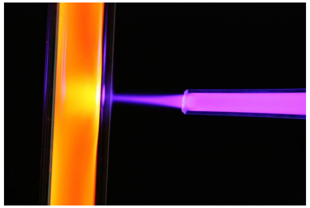
Section 2.2 – 25ème Congrès Général de la Société Française de Physique, 2019, Nantes, France

Radiant matter: the first contact...









First phenomenological descriptions of light emission from artificially ionized gases: *"radiant matter"**

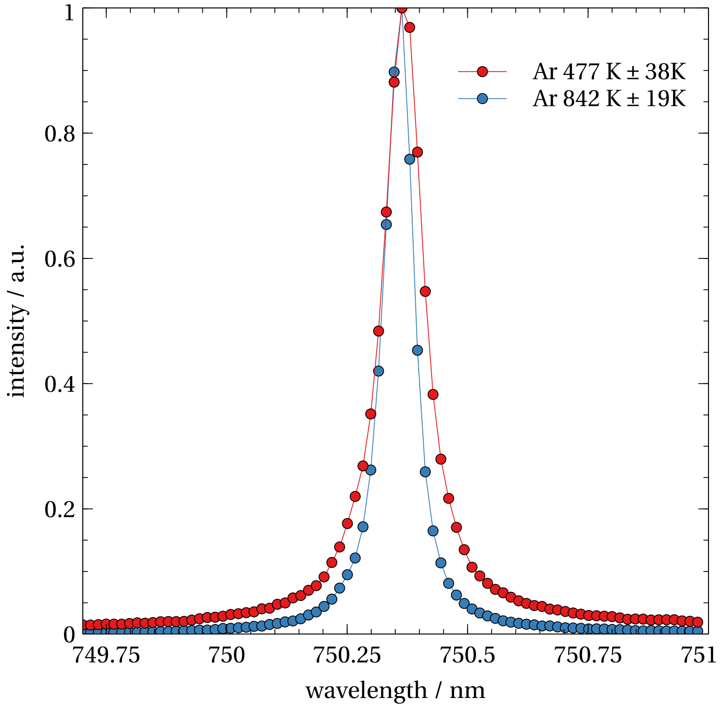
*Sir William Crookes, 1879, Philosophical Transactions of the Royal Society of London 170 135–64

Spectroscopy and line profile analysis

Types of line profile broadening*

Gaussian	Lorentzian
Instrumental	**Resonant**
Doppler	**Van der Waals**
	Stark
	Natural

- Resonance transition (dipole-dipole)
- **Reliable and non-intrusive method**



Ar resonance transition at 750.39nm ($2p_1 \rightarrow 1s_2$)

*Griem H. R., 1997, *Principles of plasma spectroscopy*, ISBN:978-0-521-45504-6

S. Djurović and N. Konjević, PSST 18, 035011 (2009)

Neutral gas temperature T_g in MicroHollow Cathod Discharge

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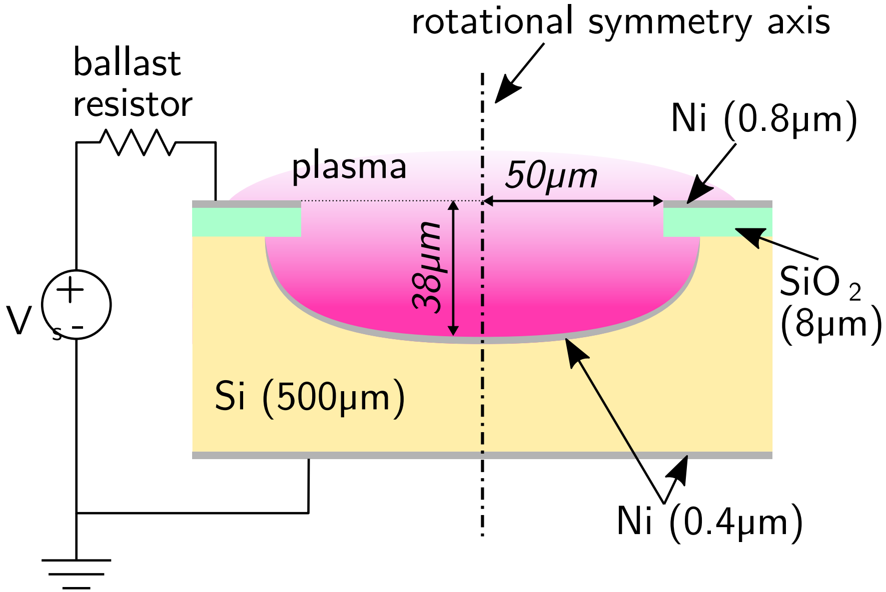
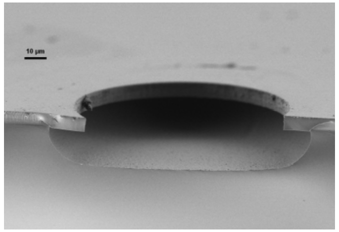
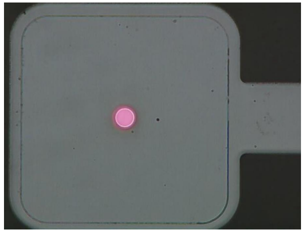
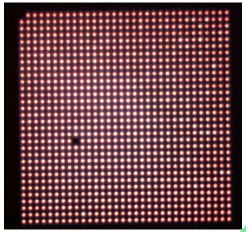
Source – Silicon based MHCD

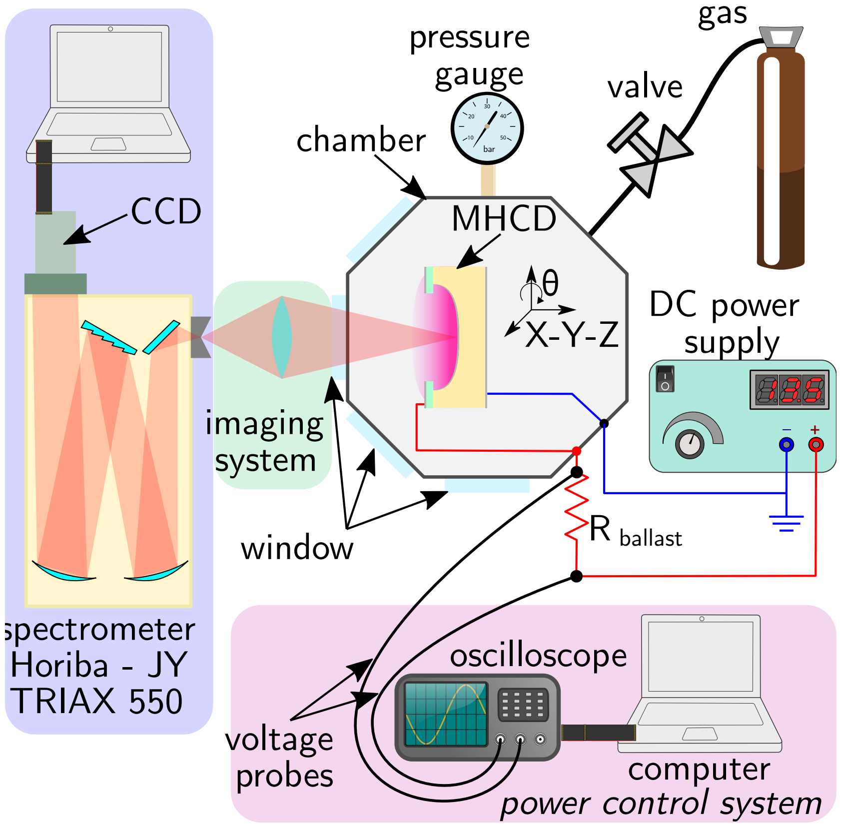
- Micro scale reactor
- Typ. Features:
  - 200 – 760 Torr,
  - 2 – 400 µA,
  - 7 – 100 mW,
  - $2.5\ .10^{-7}\ cm^{-3}$.
- He, Ar and N_2.



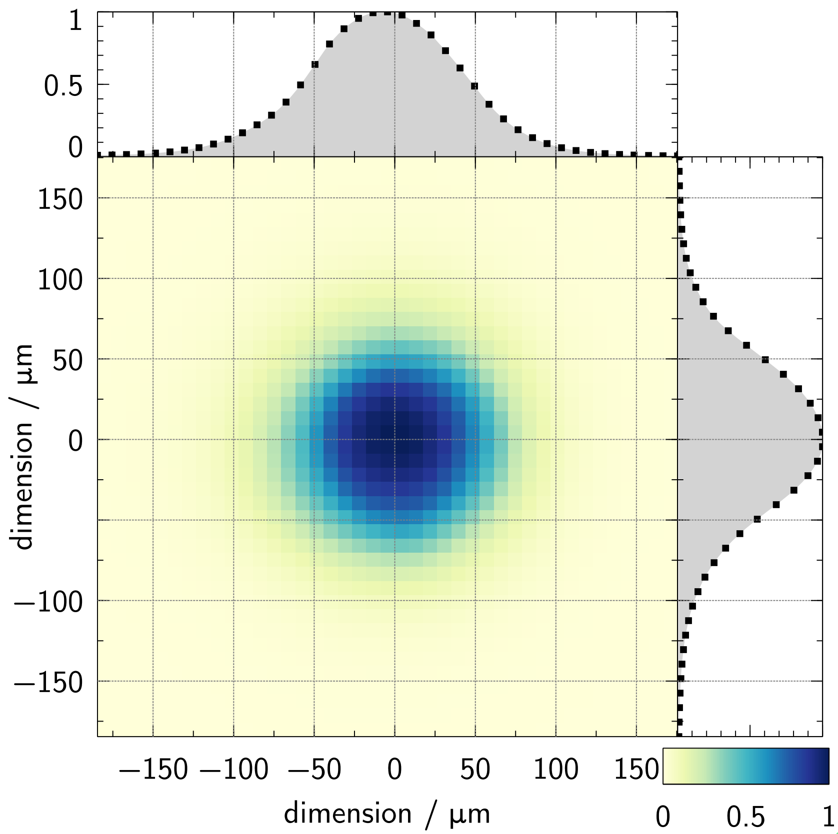




R. Michaud, et. al, PSST 27, 025005 (2018)
C.H. Sillerud, et. al., Phys. of Plas. 24, 033502 (2017).

Experimental diagnostic setup



Aberration-free image of the MHCD



OES – Atomic line profile analysis

Resonance broadening

- $$w_R = K(0,1)\frac{r_e}{\pi}\sqrt{\frac{g_G}{g_R}}\lambda_0^2\lambda_R f_R \frac{p}{k_B T_g}$$

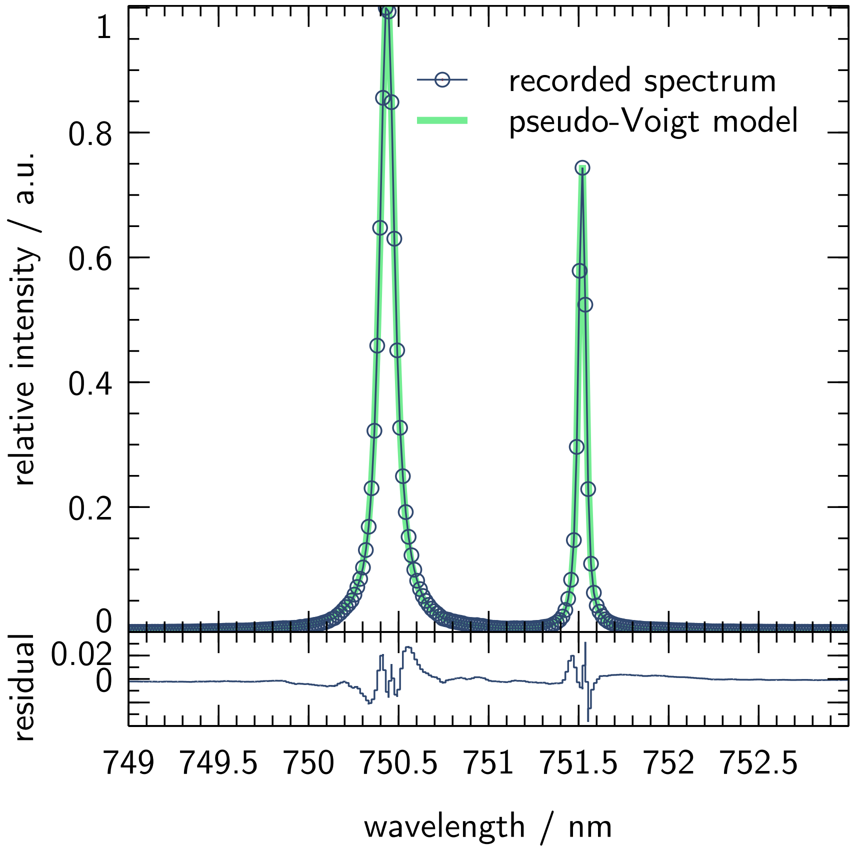
Van der Waals broadening

- $$w_{vdw} = 8.18\times10^{-12}\lambda_0^2\left(\bar{\alpha}\bar{R^2}\right)^{2/5}\left(\frac{T}{\mu}\right)^{3/10} N$$

Line shape → T_g

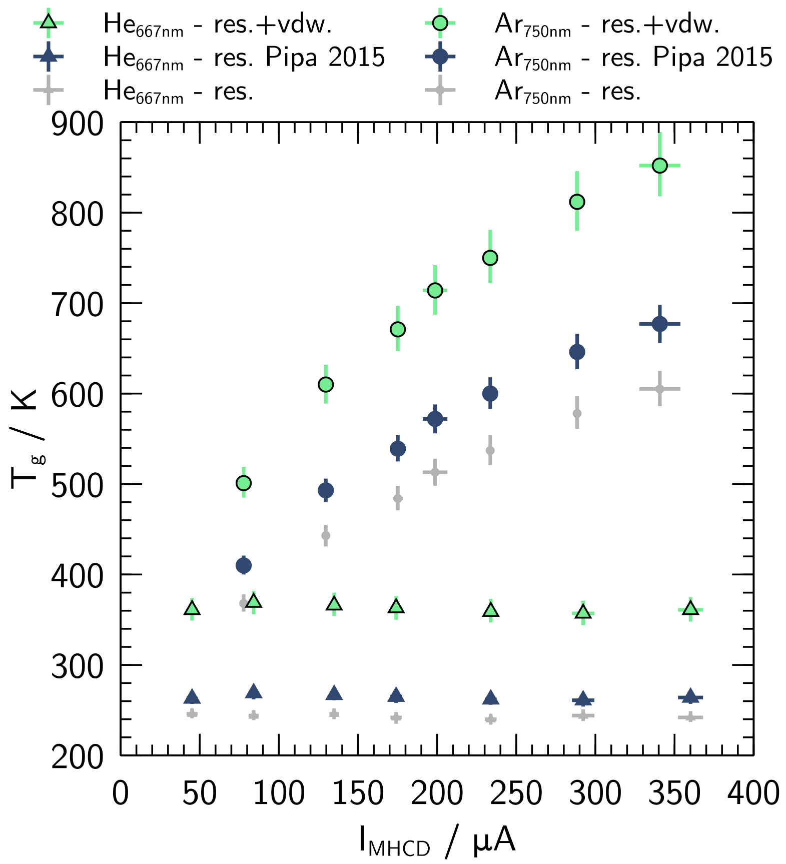
- $$w_L = \frac{\kappa_R \cdot p}{T_g} + \frac{\kappa_{vdw}\cdot p}{T_g^{0.7}}$$

$Ar_{(750.4nm)}$, $He_{(667.8nm)}$



A.V. Pipa, et. al. APL 106, 244104 (2015)
S. Djurović and N. Konjević, PSST 18, 035011 (2009)

DC MHCD in Ar and He – T_g



Spectral analysis

- K(0,1)= 1.04* *instead of 0.96*†
- Van der Waals *corrected*

Neutral gas temperature

- T_g(He) << T_g(Ar)
- T_g(He) ≈ cst. → thermal dif.
- T_g(Ar) rises with I_{MHCD}

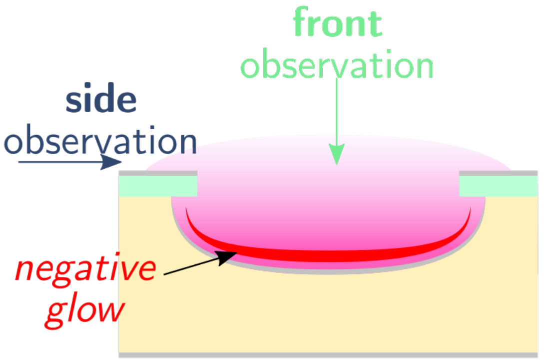
Thermal damage?

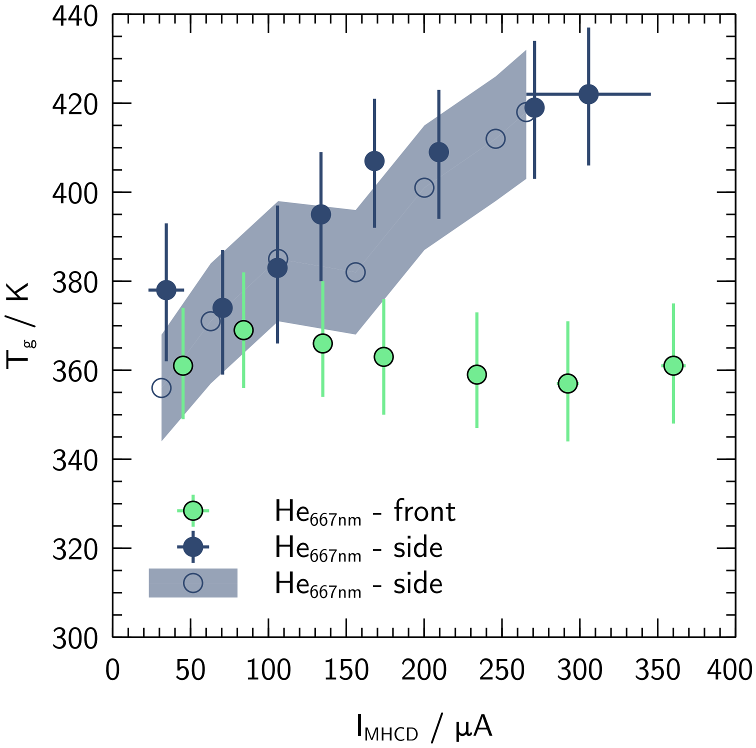
*A.V. Pipa, et. al. APL 106, 244104 (2015)

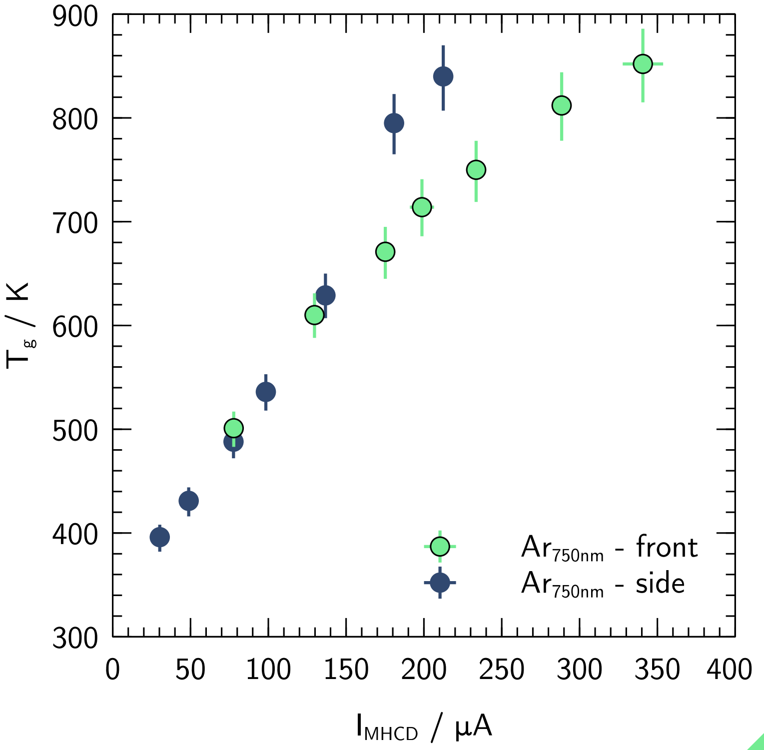
†S. Djurović and N. Konjević, PSST 18, 035011 (2009)

T_g within and out the MHCD

Investigation directions







- Front → T_g near cathode surface
- Side → T_g near plasma "core"

Hydrodynamics of Guided Ionization Waves

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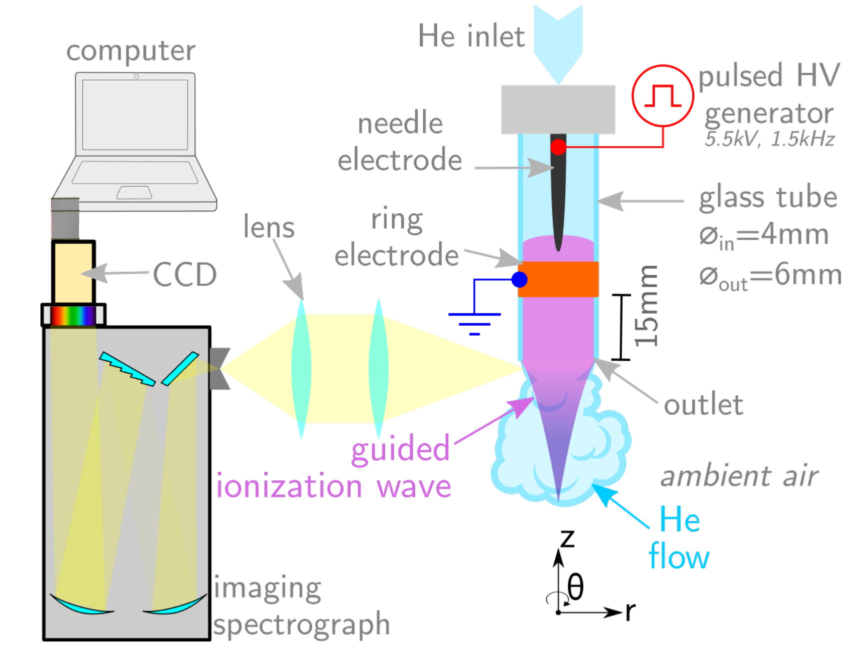
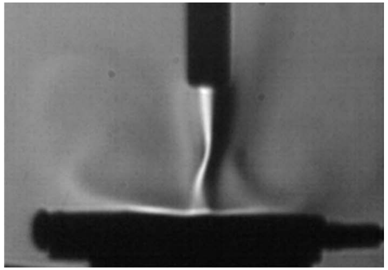
Experimental setup, $T_{rot} \approx T_g$

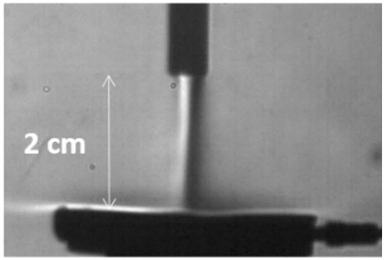
Atmospheric pressure plasma jet generating ionization waves

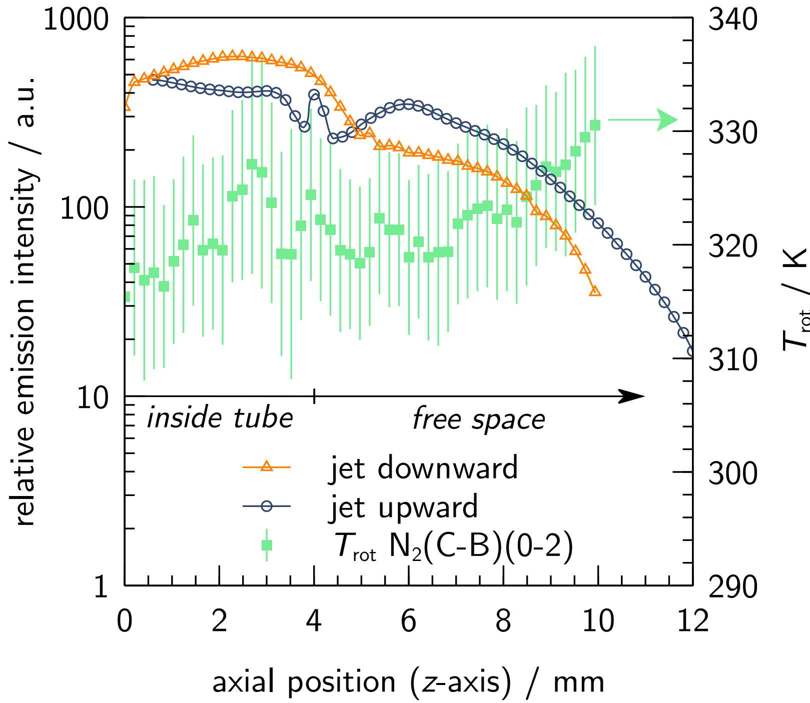


Instabilities



Channeling

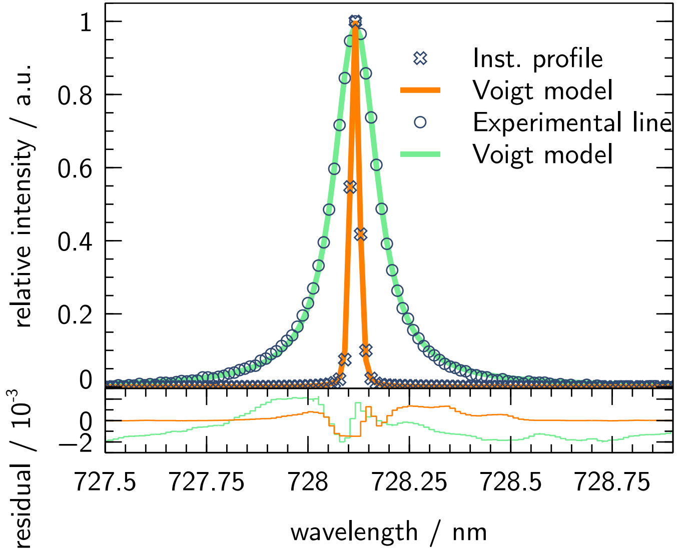


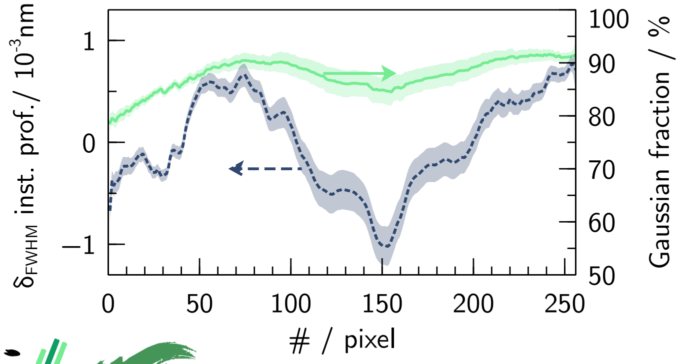


T_{rot} N_2(C-B)(0-2) $\approx T_g$

- Constant along axis

Line profile analysis: He 728.3nm





Method and assumptions

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

Table I. Calculated FWHM (w_{-}) of each broadening mechanism contributing to the line shape of the He transition ($3s^1S_0 \rightarrow 2p^1P_1$) are determined according to Djurović and Konjević[29] assuming T_g=320 K at 1013 hPa. (unit: 10^{-3} nm)

Lorentzian profile				Gaussian profile	
$w_{natural}$	w_S	w_{vdw}	w_R	w_D	$\bar{w}_{inst.}$
0.5 ± 0.2	0.6 ± 0.2^a	42 ± 5	94 ± 4	4.4 ± 0.1	25 ± 1

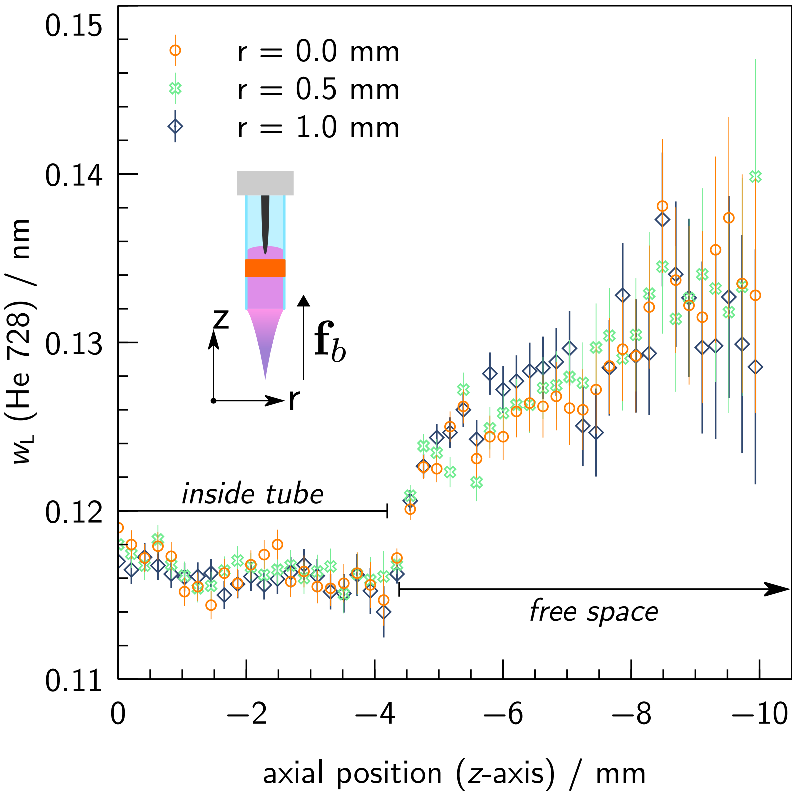
[a] Calculated for an electron temperature T_e=2 eV and a maximum electron density $n_e = 10^{14}/cm^3$.

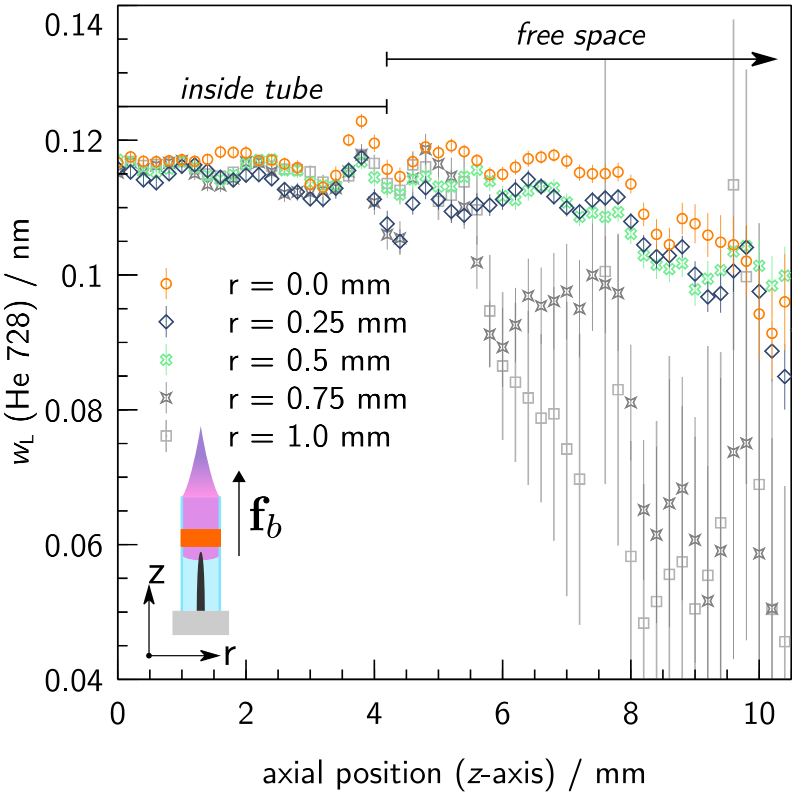
$$w_{Lorentzian} \approx w_R + w_{vdw}$$

$$w_{Lorentzian} \propto T_g \cdot N_{Helium} \Leftrightarrow p_{Helium}$$

$w_{Lorentzian}$ → hydrodynamics parameters

Results: IW flow actions & air fraction





Iseni S, Pichard C and Khacef A, 2019, *Monitoring hydrodynamic effects in helium atmospheric pressure plasma jet by resonance broadening emission line*, Applied Physics Letters, 115, 3, in press.

Concluding remarks

- OES atomic resonance broadening at high pressure
  - Non-intrusive, time & space revolved method
- Neutral gas temperature, T_g
  - Iseni S, Michaud R, Lefaucheux P, Sretenović G B, Gathen V S der and Dussart R 2019 *On the validity of neutral gas temperature by emission spectroscopy in micro-discharges close to atmospheric pressure* Plasma Sources Sci. Technol. 28 065003
- Hydrodynamics of He guided ionization waves
  - Electrohydrodynamic forces
  - In-diffusing air fraction
  - Iseni S, Pichard C and Khacef A 2019 *Monitoring hydrodynamic effects in helium atmospheric pressure plasma jet by resonance broadening emission line*, Applied Physics Letters, 115 **in press**

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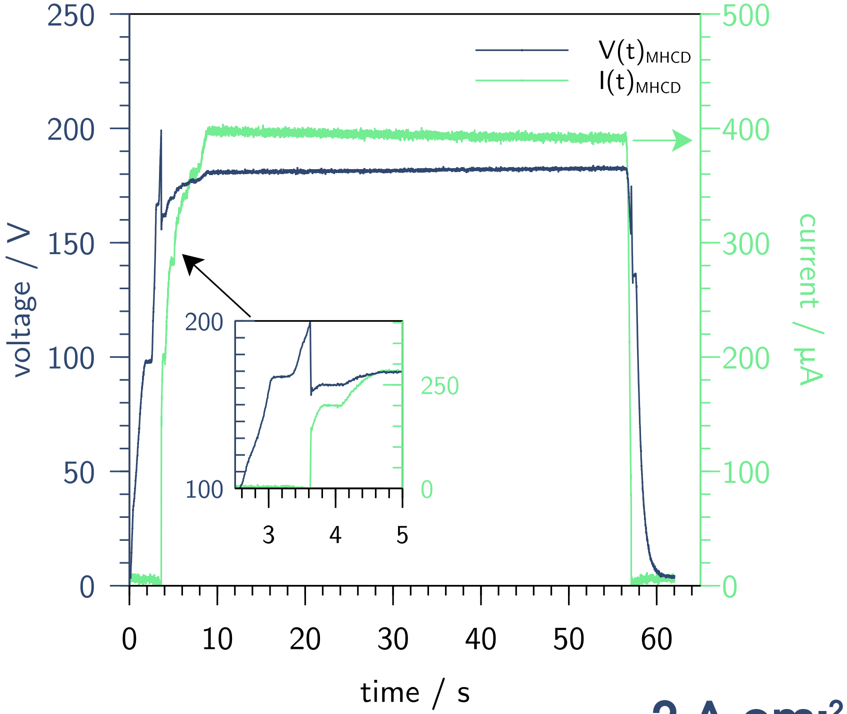
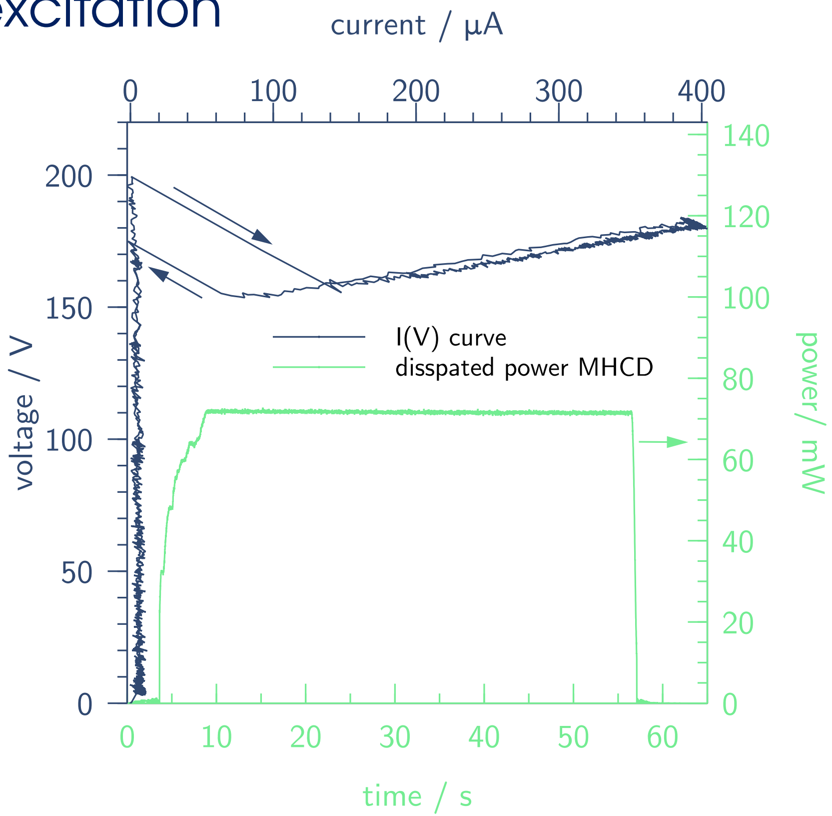
Source – electrical properties

Stabilized DC excitation

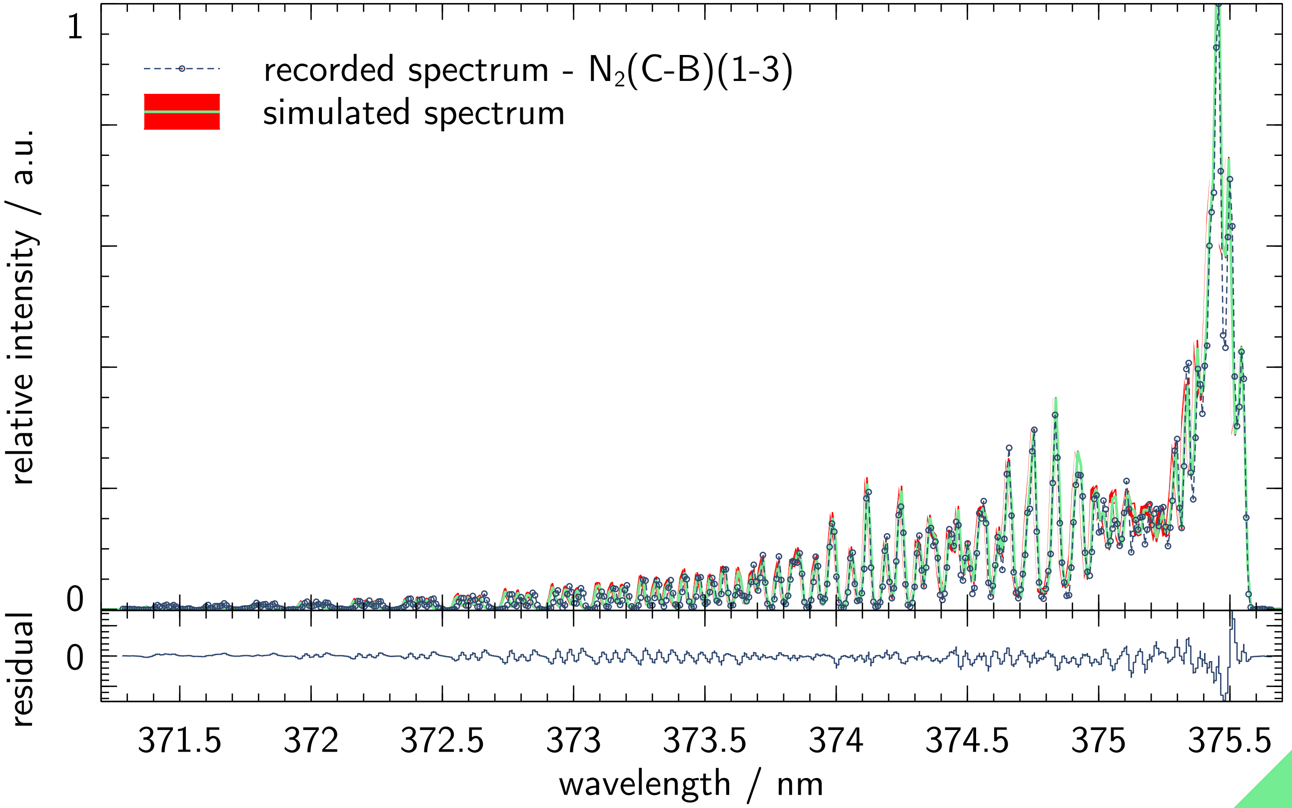




~2 A.cm^{-2}, ~5 .10^{5} W.cm^{-3}

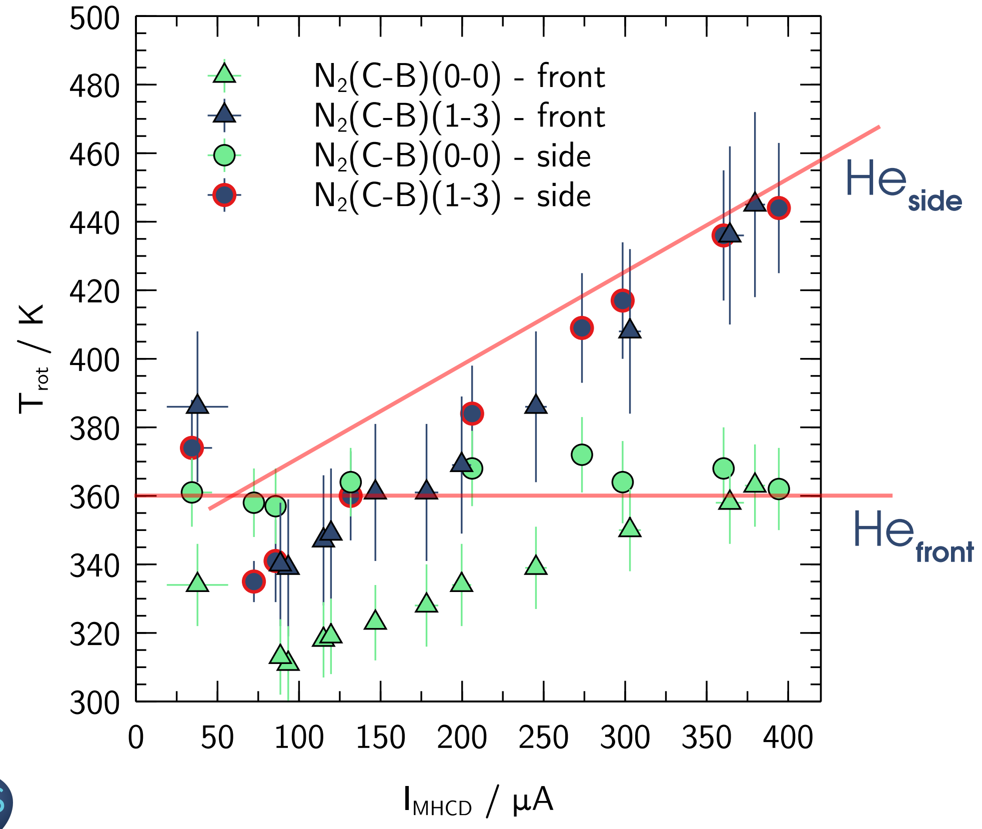
Rotational temperature – N_2(C-B)

- Relative intensity dis.
  - $I_{J''}^{J'} \propto N_{v'} S_{J''}^{J'} \left(\nu_{v''J''}^{v'J'} \right)^4 e^{\left[\frac{-hc}{k_B T_{rot}} F_{v'}^{(1,2,3)}(J') \right]}$
- N_2 rotational bands
  - N_2(C-B)(0-0) 380.5nm
  - N_2(C-B)(1-3) 375.5nm
- Optimization routine
  - Compute confidence intervals → T_{rot} ±95%
- Is $T_{rot} = T_g$…?



P.J. Bruggeman, et. al. PSST 23, 023001 (2014).
F. Roux, et. al. J. Mol. Spec. 158, 270 (1993).

T_{rot} of N_2(C-B) – front and side

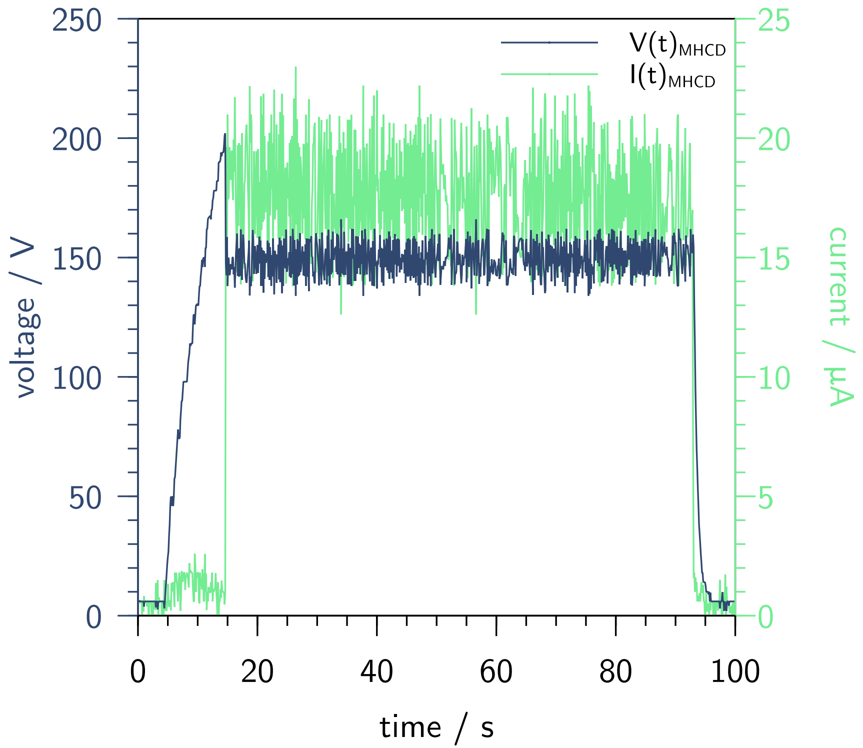


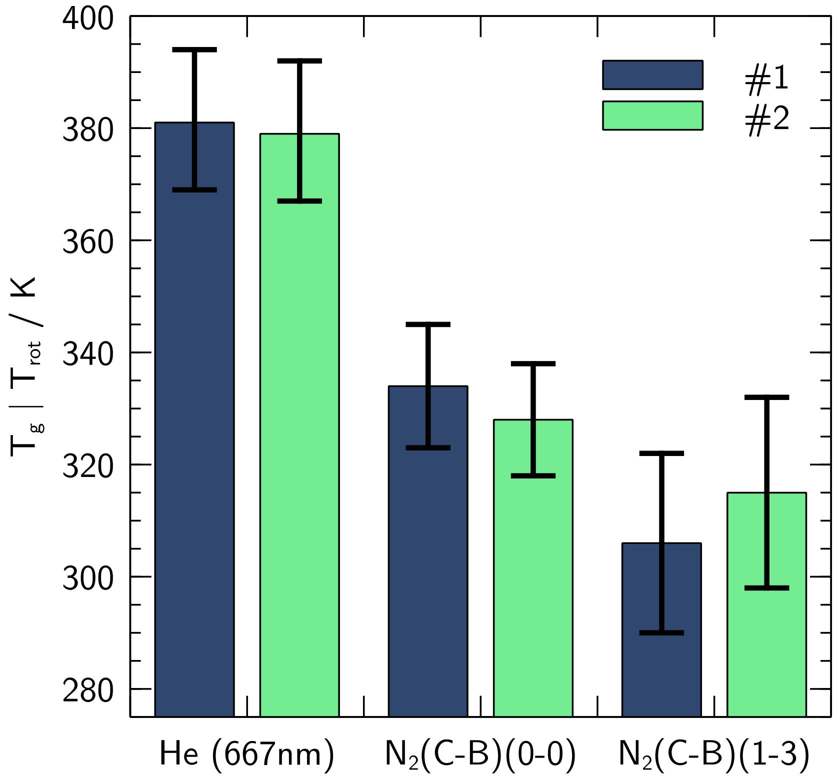
- Low current → similarity
- Discrepancy between T_{rot}
- Vibrational quenching of C-state?*
  - Not with v′=0
  - No data in He mixture
- **$T_g \neq T_{rot}$**

*Q. Wang, et. al., J. Phys. D: Appl. Phys. 38, 1690 (20 05).
*Q. Wang, et. al., J. Phys. D: Appl. Phys. 40, 4202 (2007).
P.J. Bruggeman, et. al. PSST 23, 023001 (2014).

More time to relax → self-pulsing ?

Self-pulsing* electrical features

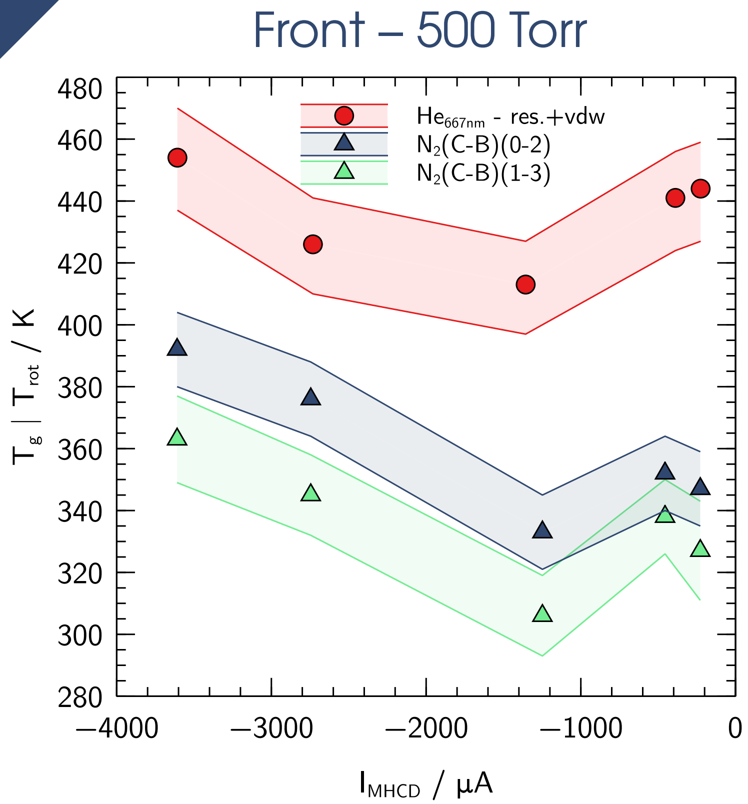


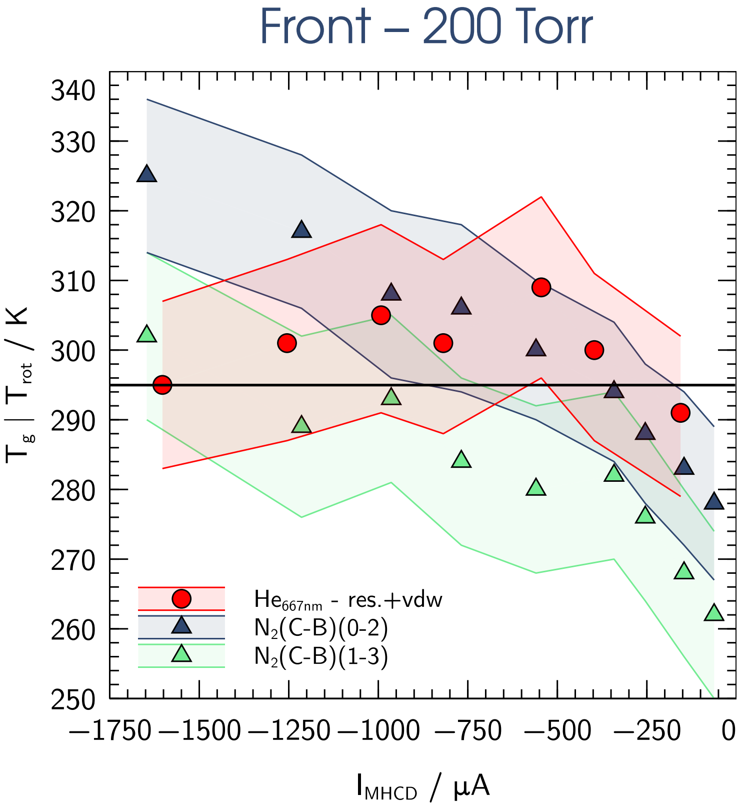


I_{MHCD}=17±2 µA, P_{MHCD}=2.5±0.5 mW

* P. Chabert, et. al. JAP 108, 113307 (2010). | C. Lazzaroni and P. Chabert, JAP 111, 053305 (2012).

Reversed polarity → *anode* cavity: T_{rot}





- Cold anode cavity
- 500 Torr
  - $T_{rot} \neq T_g$
- 200 Torr
  - $T_{rot} \approx T_g$
- Pop. Mechanism N_2(C)-state
- Same trends!

!! T_g (res+vdw) → ~293K = lab temperature!!