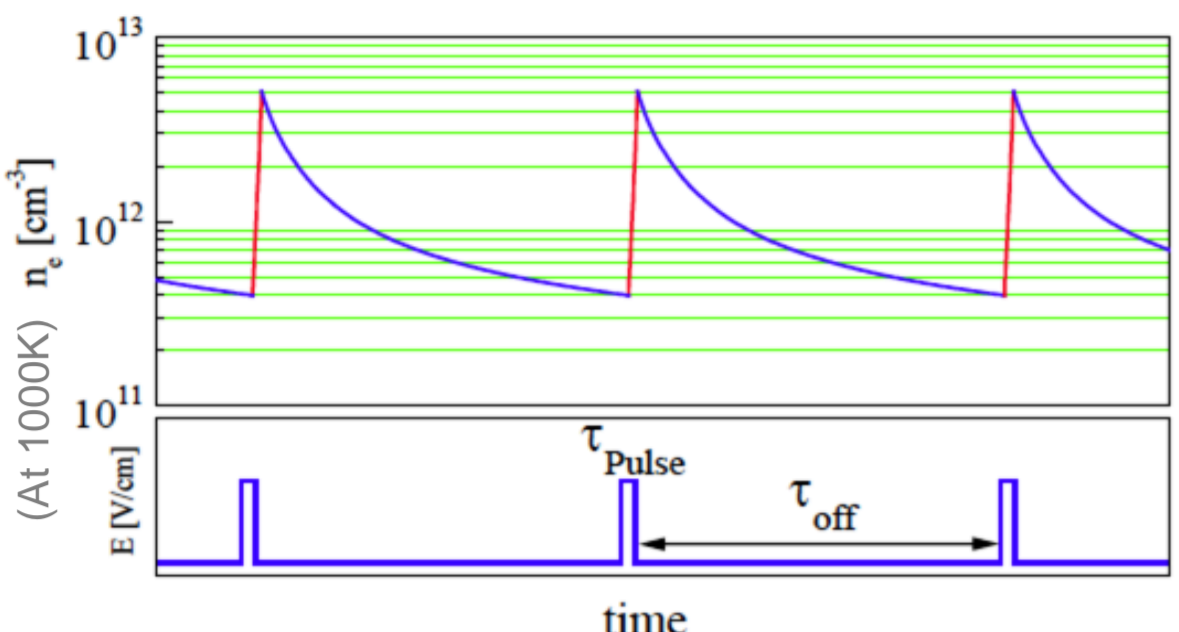


# Nanosecond Repetitively Pulsed Glow Discharges in Atmospheric Pressure Air at 300K

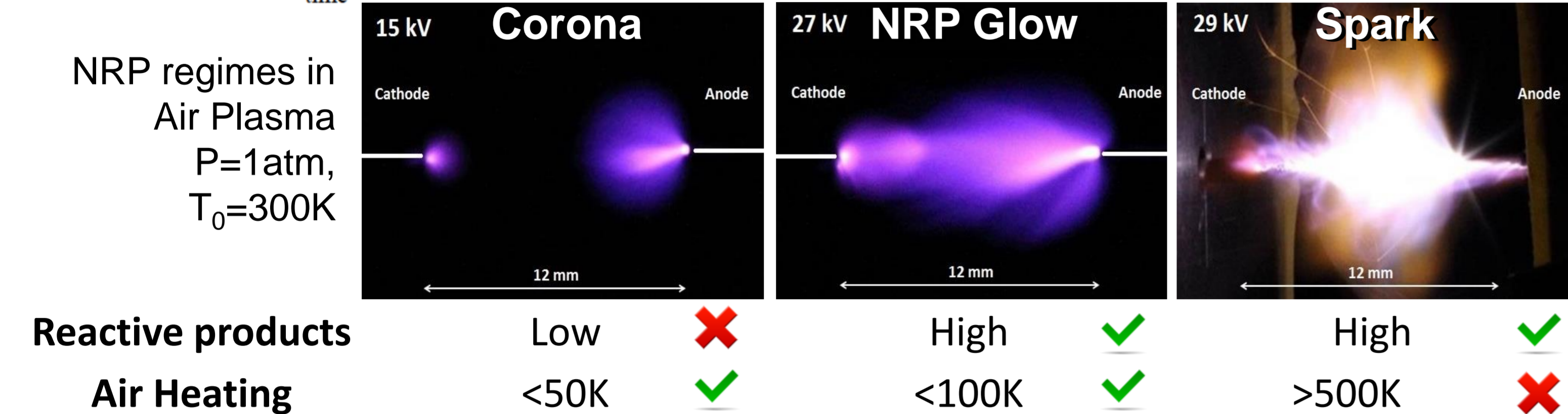
## 1. Motivation

Produce **high density** of reactive species (ozone, nitric oxides) at **T~300K** in **atmospheric pressure air**, as a cost effective process for biodecontamination



NRP strategy:  $\tau_{pulse} \ll \tau_{plasma\ relaxation}$

- **High E/N** → High density of reactive species
- **Short pulses** → Can avoid arcing & heating
- **Low average power** → Energy efficiency



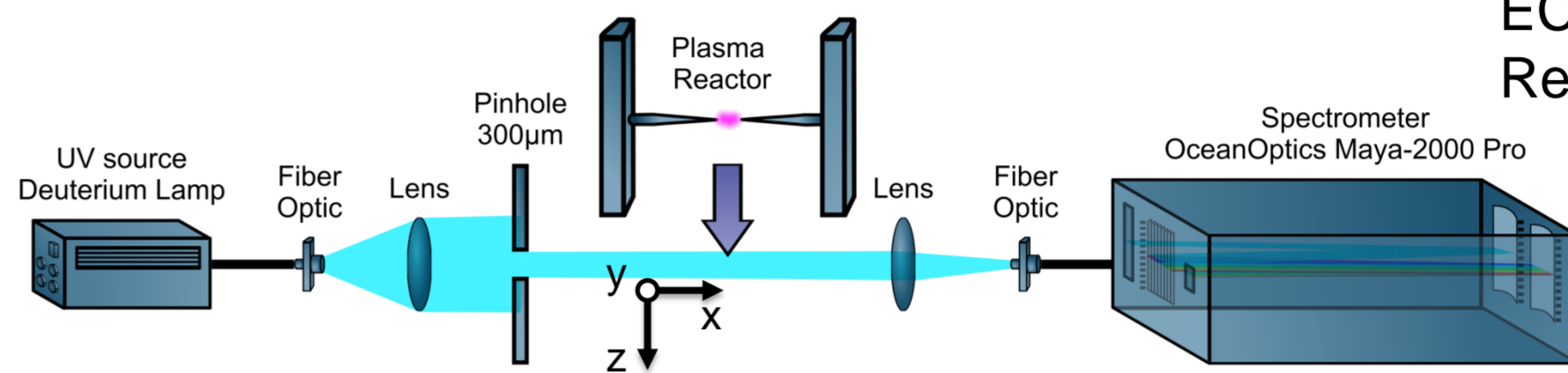
## 2. Experimental Setup

Discharge characteristics

- 2 electrodes (pin-to-pin), gap  $d=1-15\text{mm}$
- FID Technology FPG 30-100MS Pulsar
- $f=1-100\text{kHz}$ ,  $V=5-30\text{kV}$
- Pulse duration  $\tau_{90}=10\text{ns}$
- Flow: dry air (3%),  $v=1-10\text{m/s}$

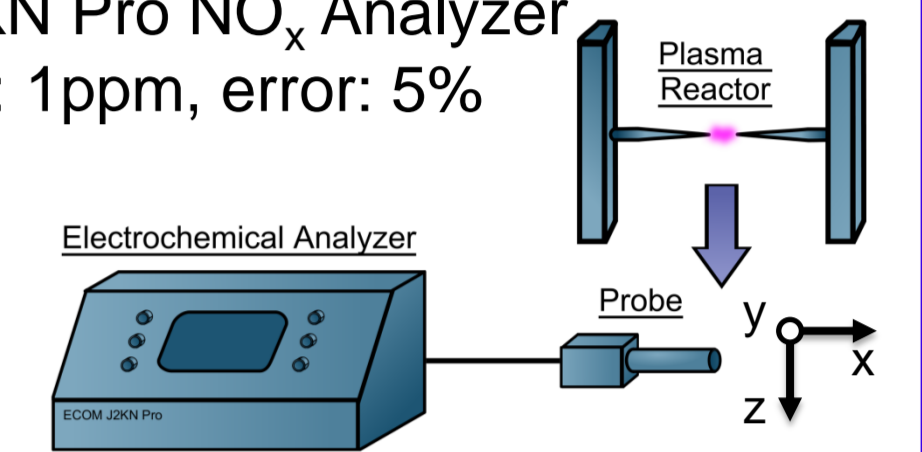
Optical Diagnostics

- Ozone UV absorption spectroscopy
- Hartley bands, 200-300 nm
- OceanOptics Maya2000 Pro Spectrometer
- Spatial resolution: 300 $\mu\text{m}$ , spectral resolution: 1nm



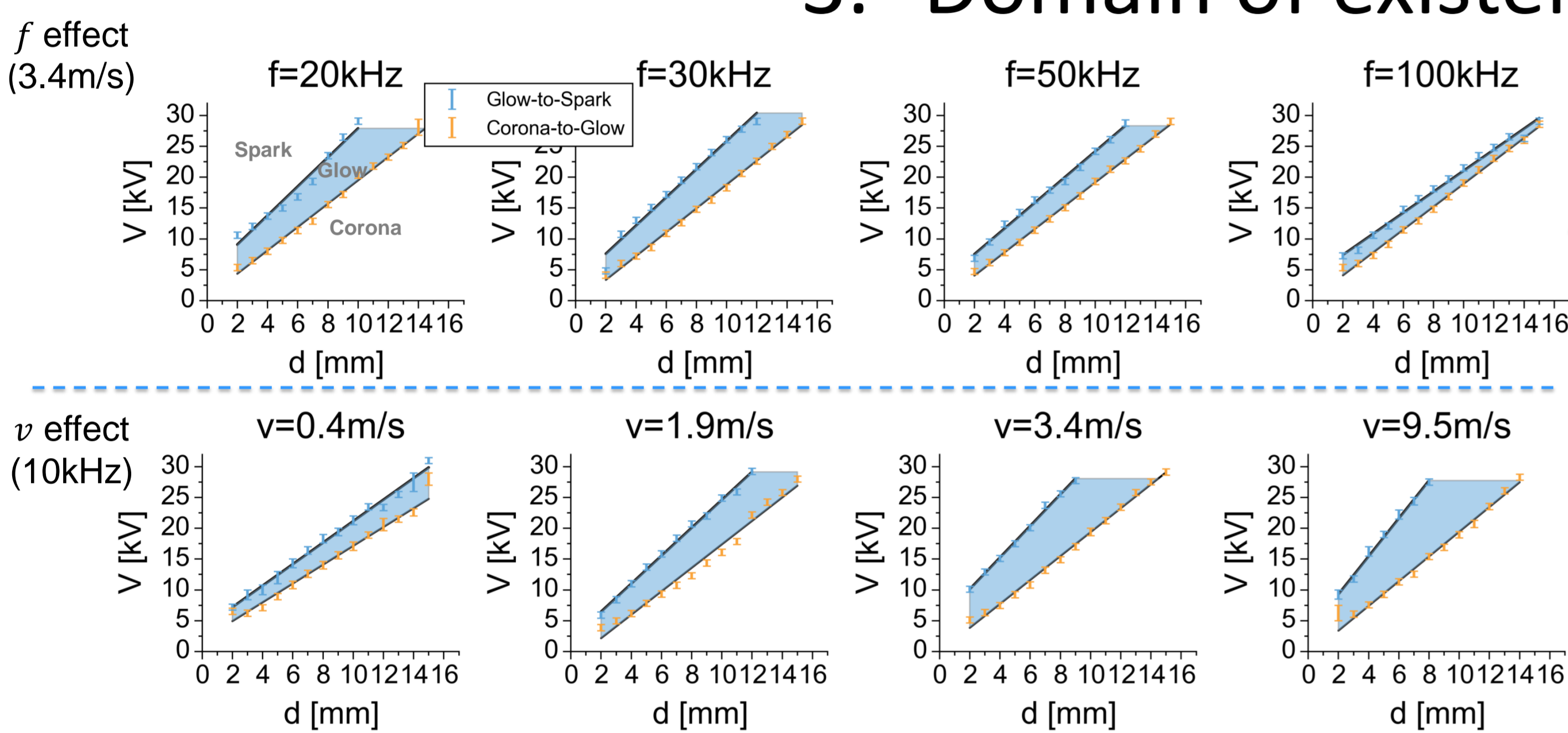
Electrochemical Diagnostics

- NO<sub>x</sub> measurements
- ECOM J2KN Pro NO<sub>x</sub> Analyzer
- Resolution: 1ppm, error: 5%



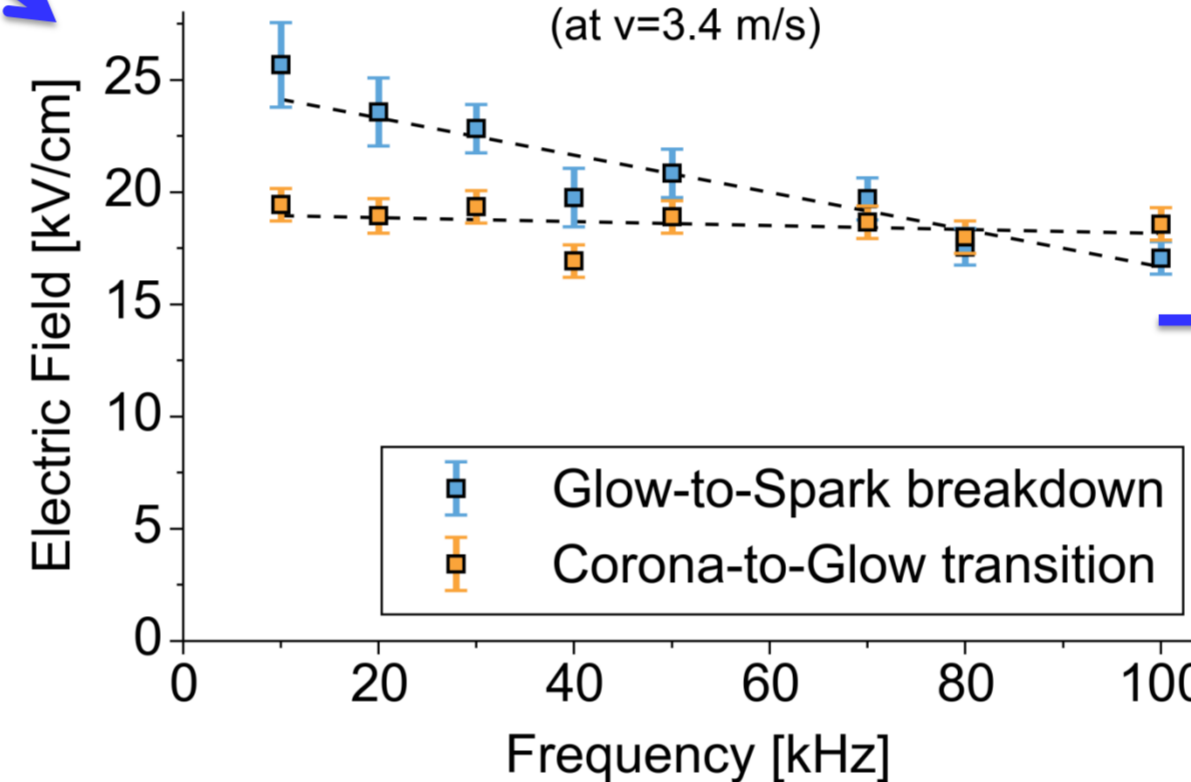
Temperature measurements Discharge: OES on N<sub>2</sub>(C). Post-discharge: Thermocouple (K)

## 3. Domain of existence of the NRP Glow Regime

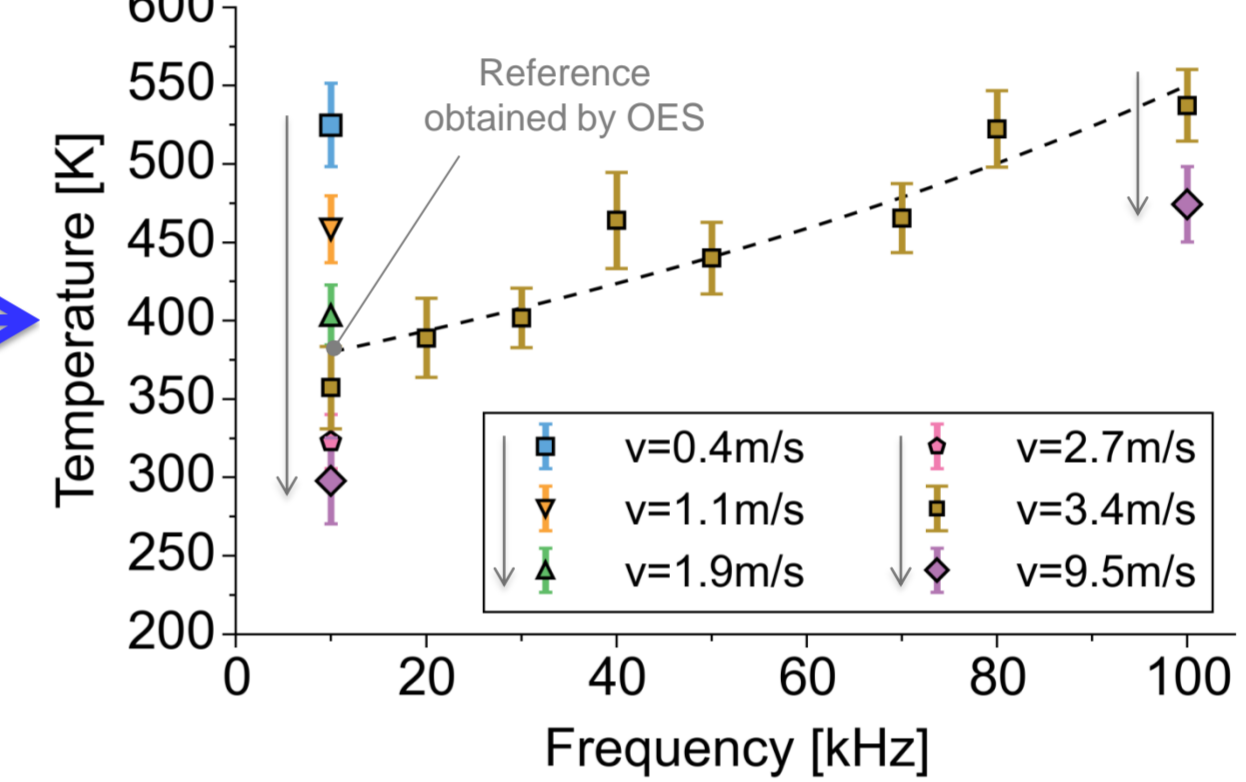


$$V_{breakdown} = \frac{(E/N)_{break} \cdot N \cdot d + V_{CF}}{\sim \text{constant}} \begin{cases} E_{CG} \text{ constant} \rightarrow \text{no heating} \\ E_{GS} \searrow \text{ with } f \text{ and } v^{-1} \rightarrow \text{heating effect} \end{cases}$$

Frequency dependency (at  $v=3.4\text{ m/s}$ )

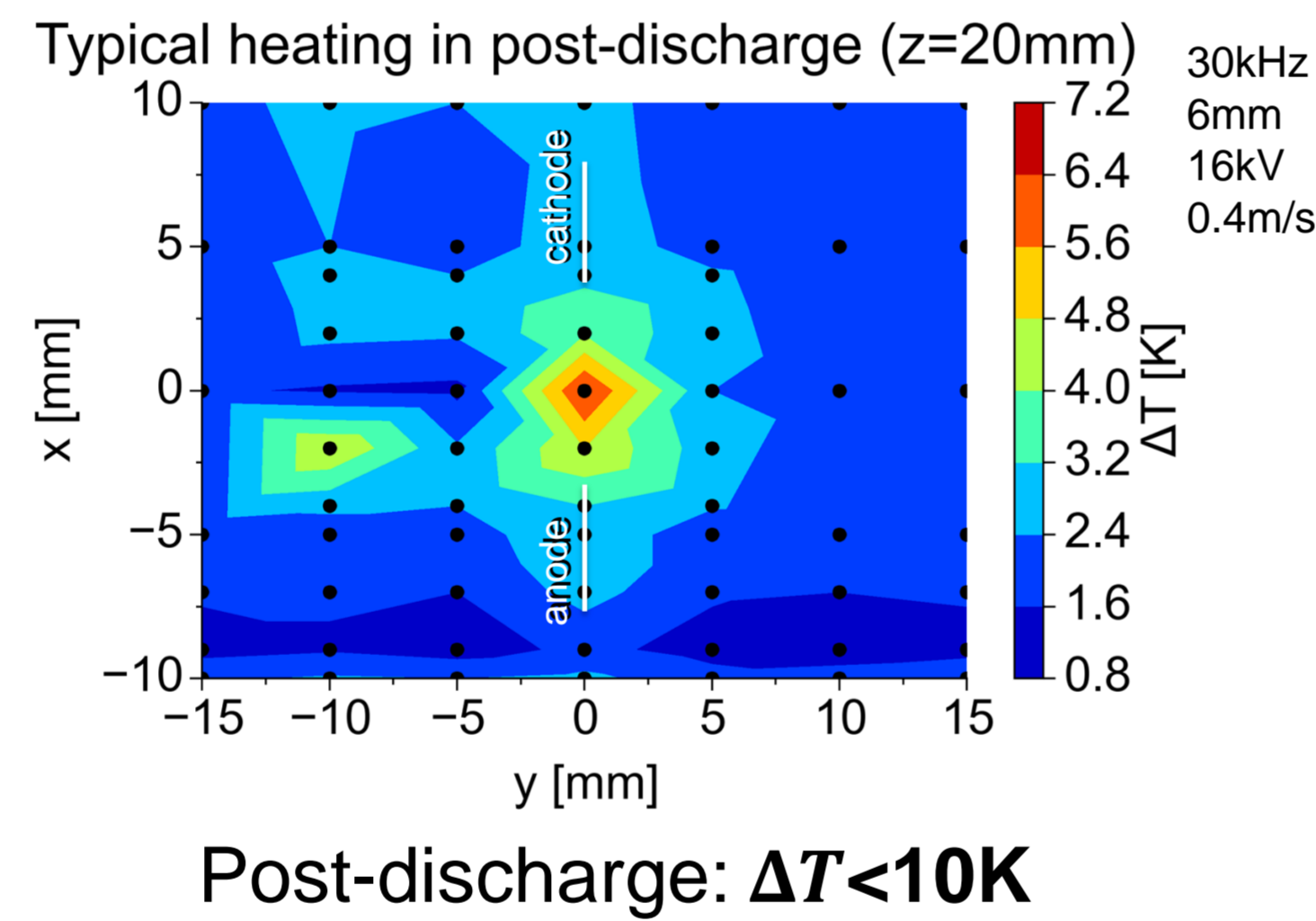
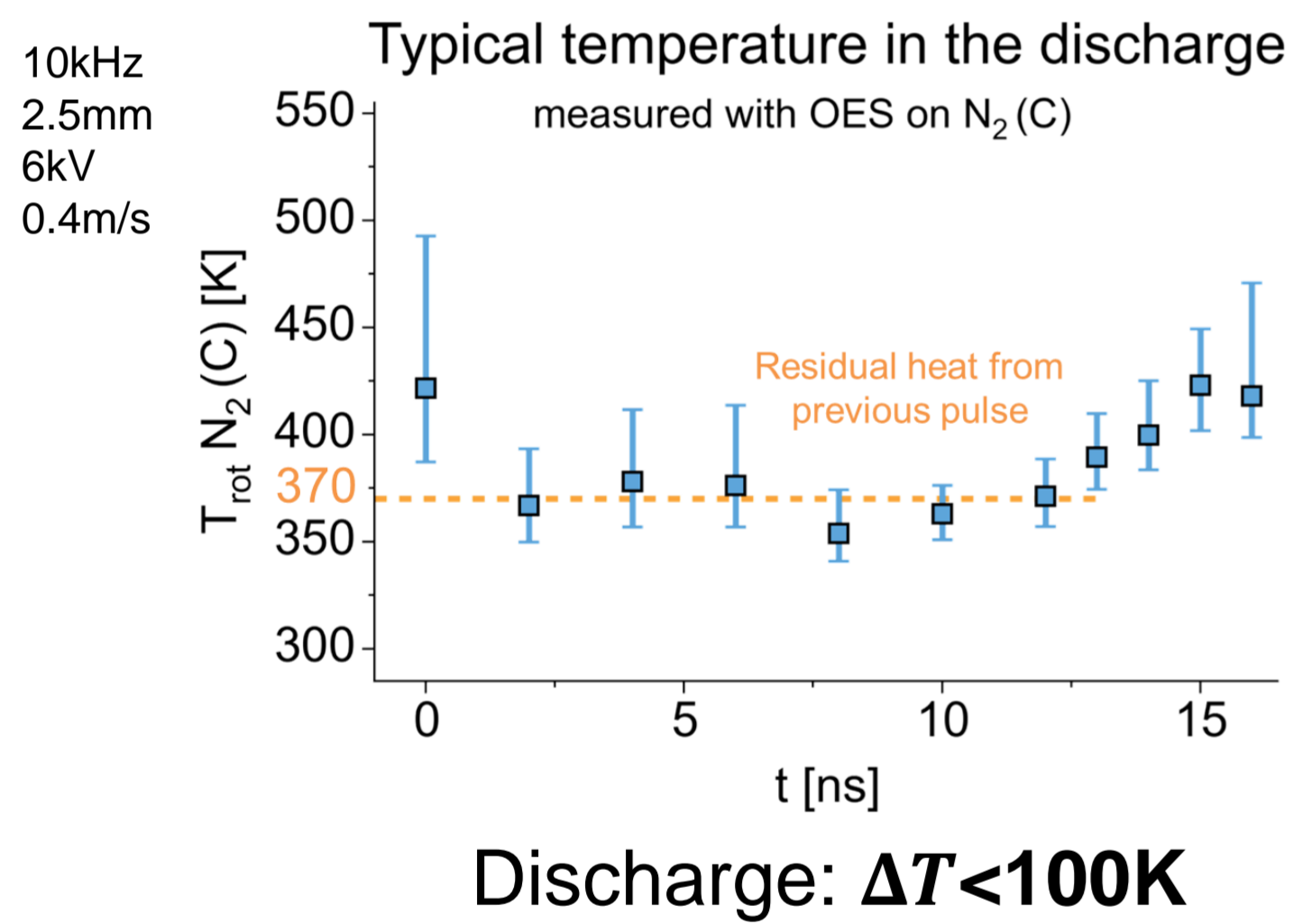


Glow Temperature

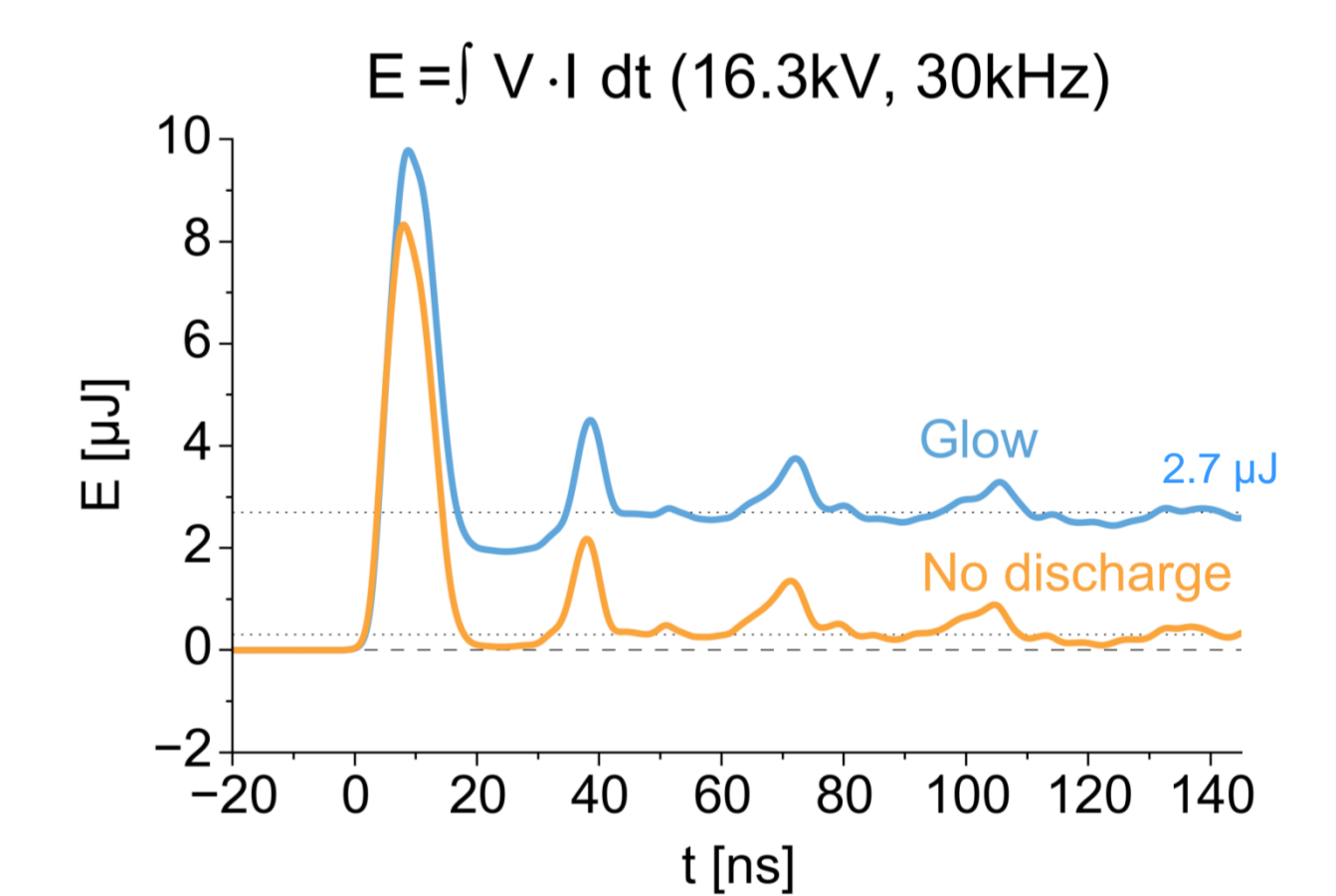
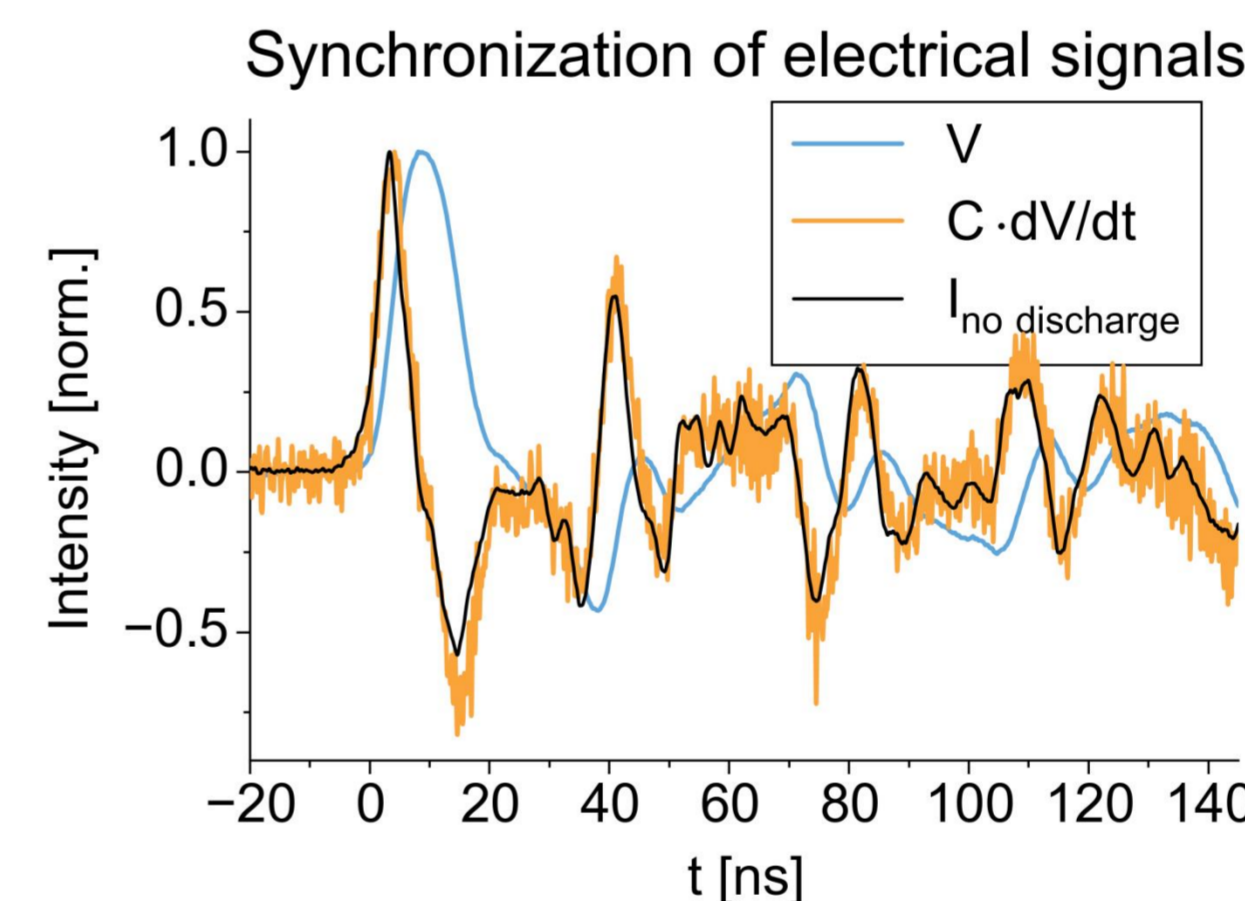


Limited  $\Delta T$  can be achieved in large volumes ( $d > 15\text{mm}$ ) at high  $f$  (100kHz) and high  $v$  (10m/s)

## 4. Heating

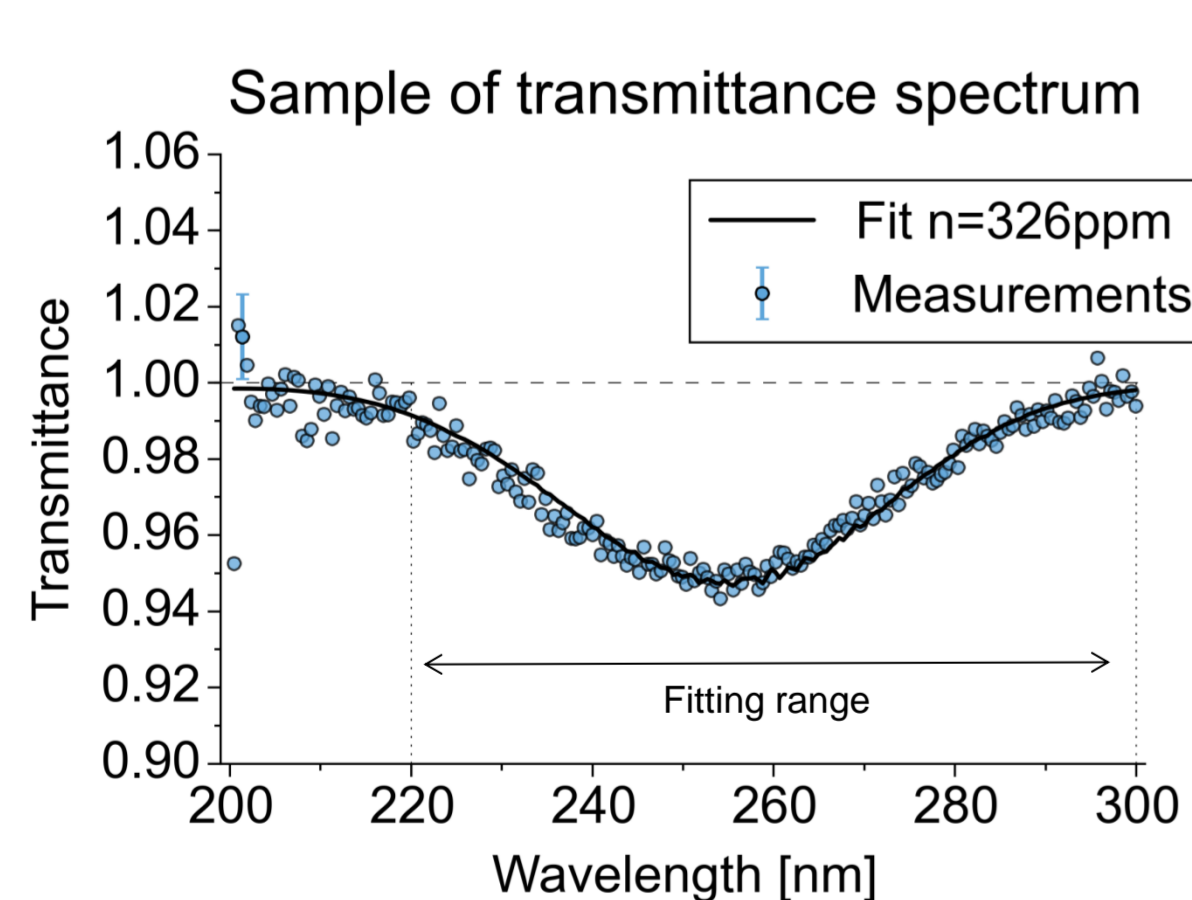


## 5. Energy Deposited



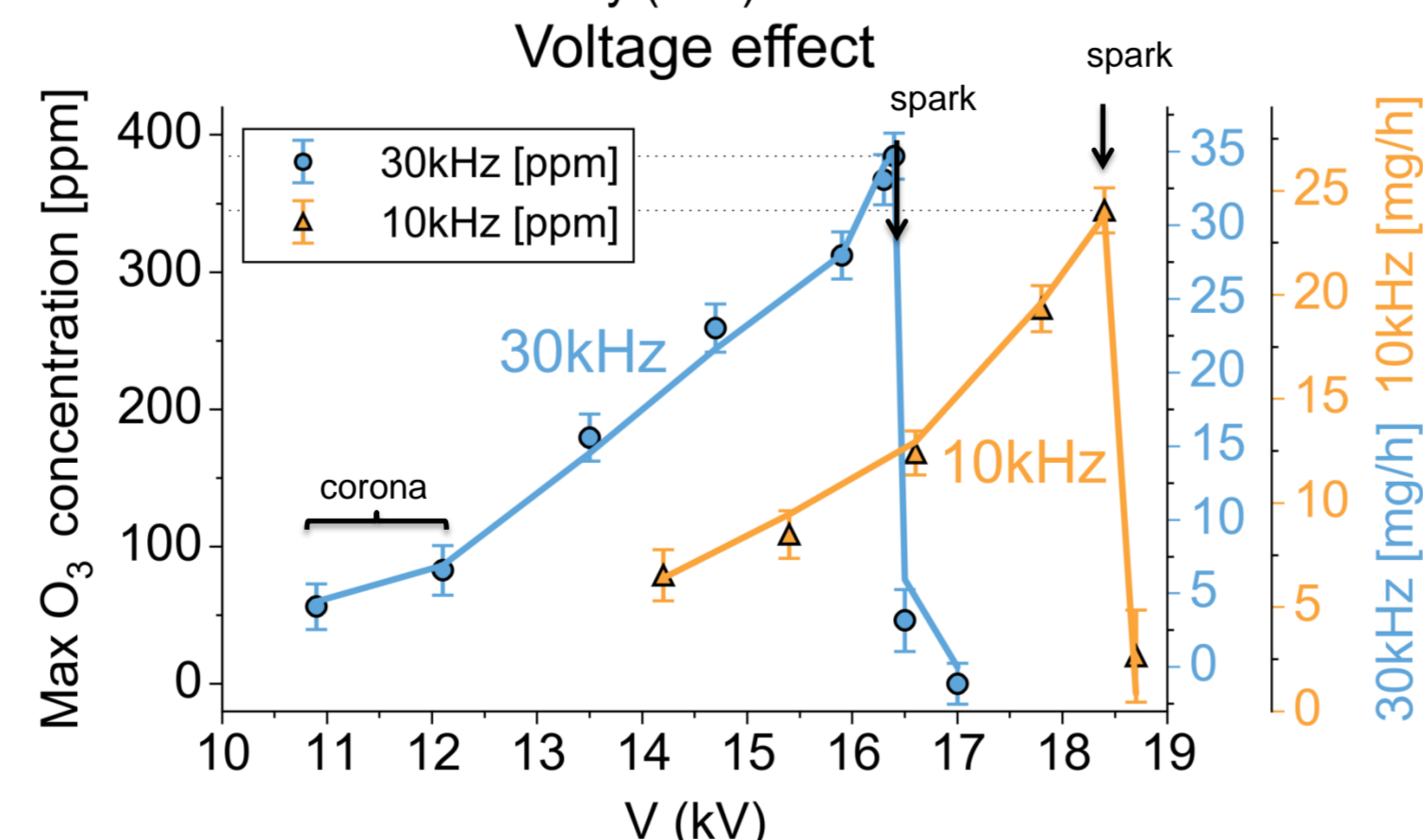
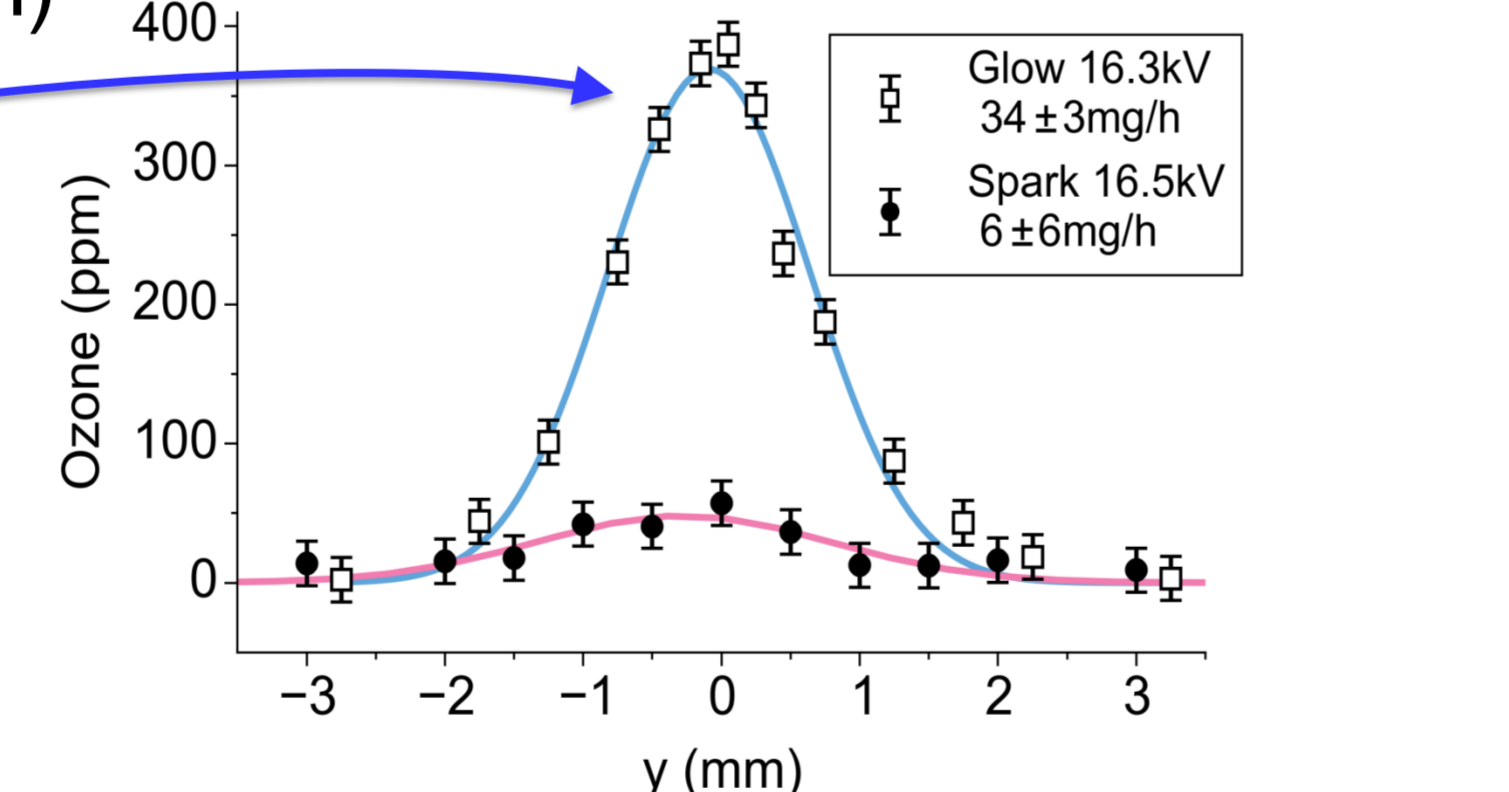
## 4. Active Species

Ozone in the post-discharge ( $z=5\text{mm}$ )

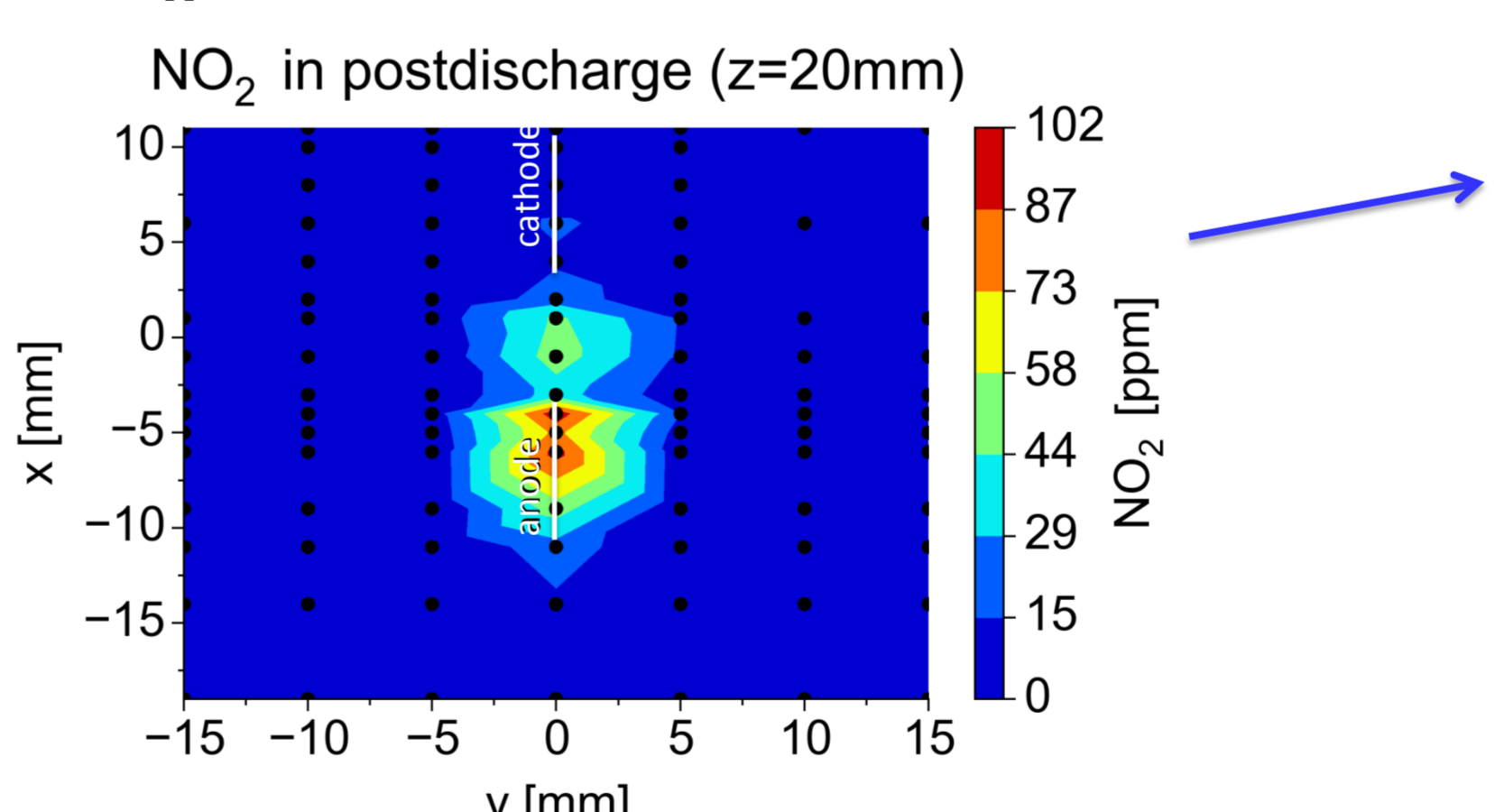


- O<sub>3</sub> increases with  $V$  and  $f$  up to 400ppm, 35mg/h
- In the spark regime, O<sub>3</sub> disappears due to heating
- At  $z=20\text{mm}$ : 100ppm, 35mg/h  $\rightarrow$  diffusion effect

Ozone concentration ( $f=30\text{kHz}$ )

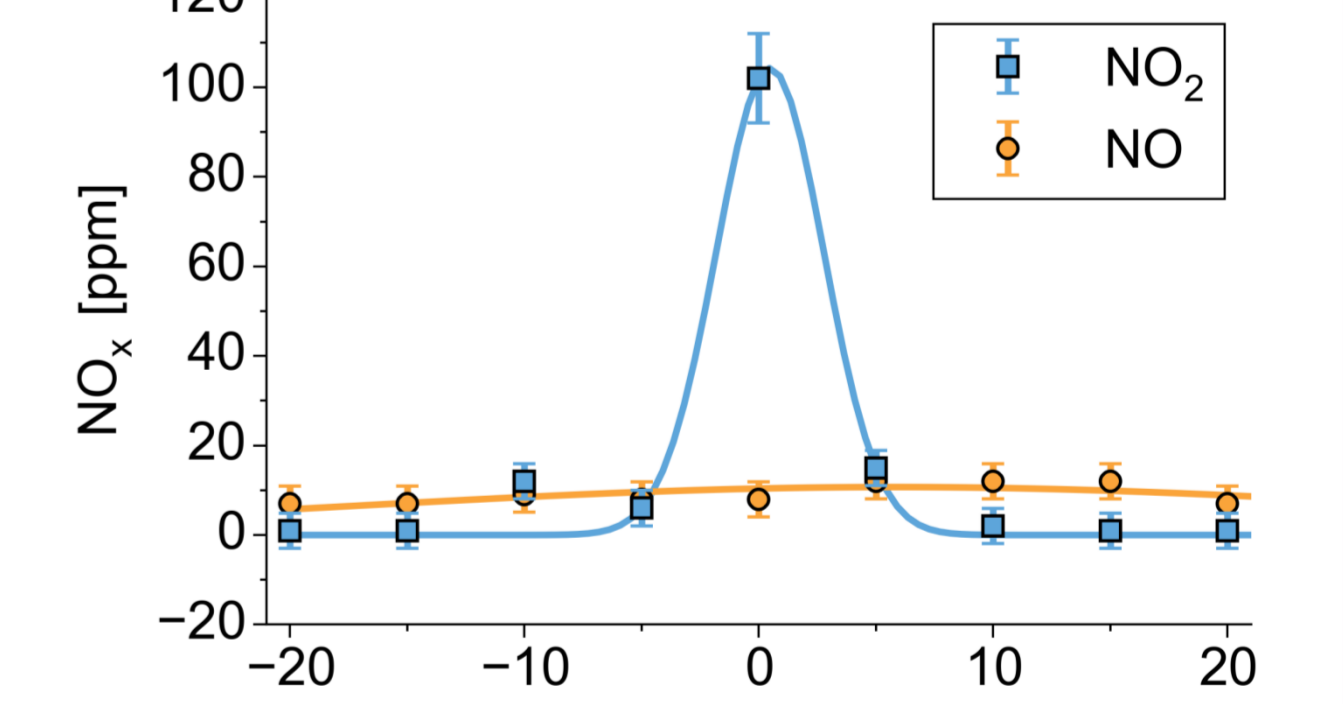


NO<sub>x</sub> in the post-discharge ( $z=20\text{mm}$ )

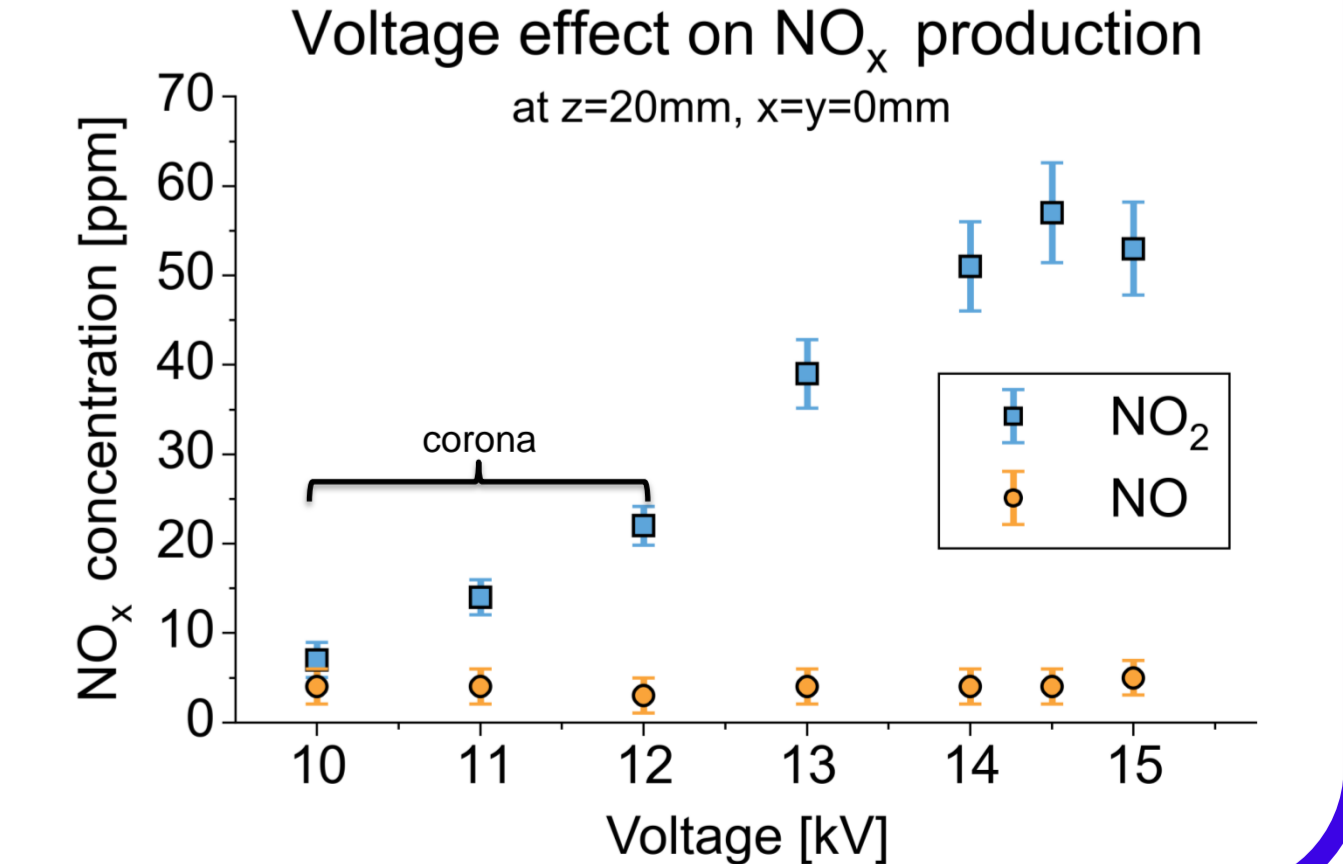


- Mostly NO<sub>2</sub> is present in the post-discharge.
- Low NO concentration can be explained by the low temperature and the presence of ozone

Max NO<sub>x</sub> concentration ( $z=20\text{mm}$ )



Voltage effect on NO<sub>x</sub> production at  $z=20\text{mm}$ ,  $x=y=0\text{mm}$



## 7. Comparison

	Gas	W	slm	z (mm)	$\Delta T$	O <sub>3</sub> (ppm)	NO (ppm)	NO <sub>2</sub> (ppm)
<b>NRP Glow</b>	Air	~0.1	1-2	20	10	100	10	100
$\mu\text{w}$ APPJ (Van Gessel 13)	He 3%Air	18	6	20	220	n/a	35	n/a
RF APPJ (Van Gessel 13)	Ar 1%Air	3	1	20	10	n/a	16	n/a
RF APPJ - Kinpen (Iséni 14)	Ar 1%Air	~1	1	7.5	150	~60	5.3	2.0

## 8. Conclusions

- NRP Glow: **large volumes** ( $d > 15\text{mm}$ ) at  $f > 100\text{kHz}$  and  $v > 10\text{m/s}$
- **Pure air** with low heating in the post-discharge ( $< 10\text{K}$  at 20mm)
- **Lower energy cost** and production rates similar to other techniques

## 9. References

- D.Z. Pai, D.A. Lacoste, C.O. Laux, "Transitions between corona, glow, and spark regimes of nanosecond repetitively pulsed discharges in air at atmospheric pressure". J. Phys. D: Appl. Phys. 107 (2010)
- A.F.H. Van Gessel, K.M.J. Alards, P.J. Bruggeman, "NO production in an RF plasma jet at atmospheric pressure", Journal of Physics D: Applied Physics 46 (2013)
- S. Iséni et al. "Nitric oxide density distributions in the effluent of a RF argon APPJ: effect of gas flow rate and substrate". New Journal of Physics 16 (2014)