

From Discharge Physics to Reactive Chemistry: an Integrated Diagnostic Path to Plasma Agriculture

*A multi-diagnostic framework for atmospheric-pressure DBD
reactors*

DOMENICO ACETO

M. Ambrico, G. Dilecce, P. F. Ambrico

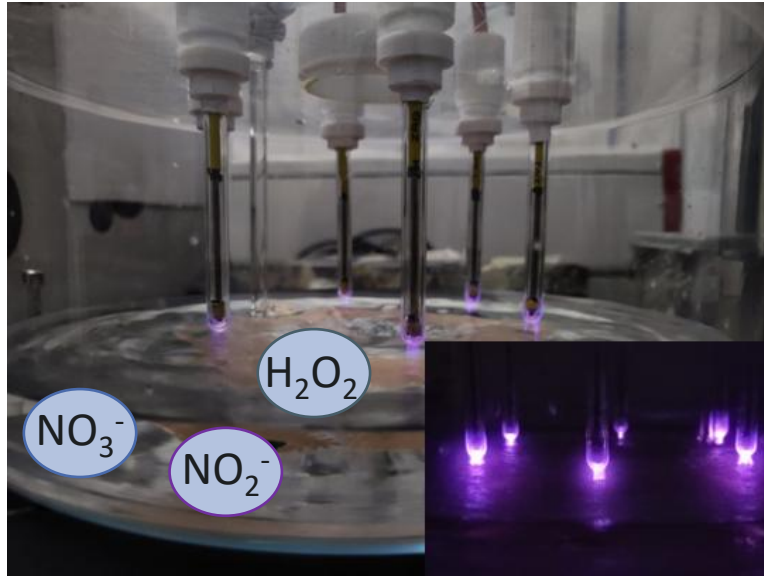
ISTP CNR – Bari, Italy

ICFDT – Frontiers in Diagnostic Technologies

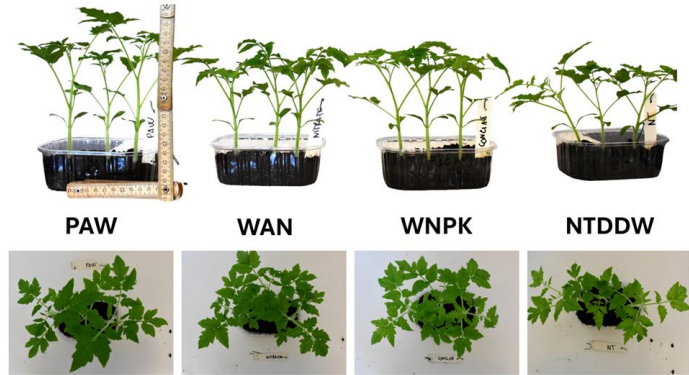
19/10/2026 - Frascati

Plasma-Activated Water

Plasma Activated Water: indirect treatment
RONS produced in the **plasma** to substrates.

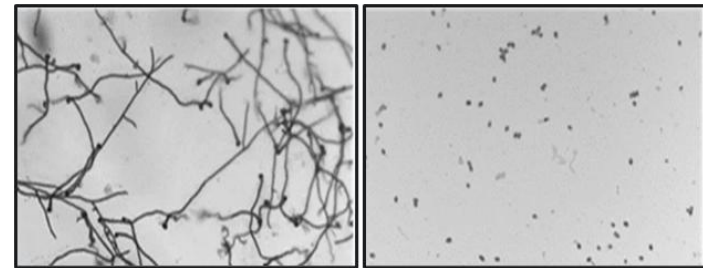


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Fertilization

Decontamination



Plasma-Activated Fog

PAW shortcomings in decontamination

- Chemical stability during storage
- Washing wet-sensitive produce may damage them
- Treating large volumes of water makes the process difficult to scale up



Plasma-Activated Fog (PAF)

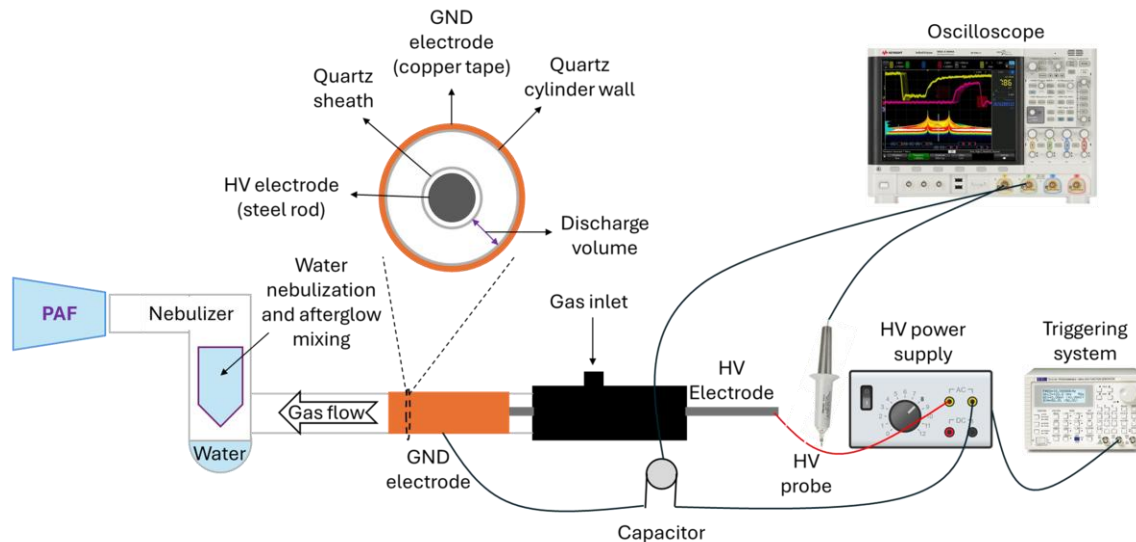
- Same RONS chemistry carried on an aerosol → very large gas-liquid interface
- Delivered immediately without wetting and with no thermal or mechanical stress → suits delicate produce
- scales more naturally toward industrial post-harvest



Objective

Thorough physico-chemical characterisation of the process for its full optimisation.

PAF reactor design



Reactor

Coaxial DBD + medical glass nebulizer,
double-distilled water

Power supply

AC, 19.5 kV peak voltage

Burst mode

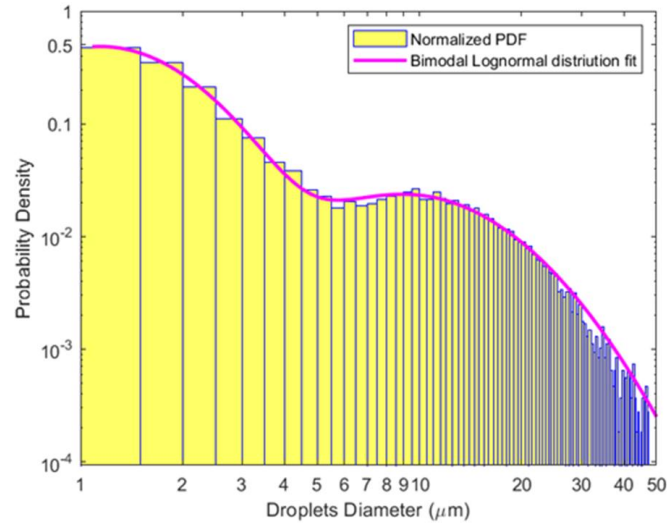
15 cycles @ 25 kHz · 500 Hz repetition ·
30% duty cycle

Feed gas

10 sLm ambient air → fog saturates the
treatment chamber

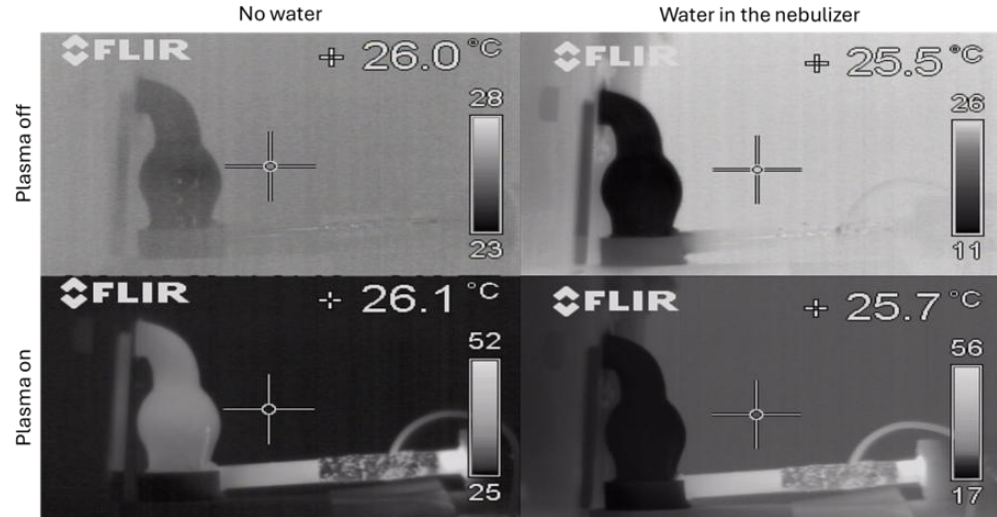
Design choice: the discharge zone sits upstream of the nebulization chamber → stable discharge, humidity-robust electrical characteristics, low experiment-to-experiment variance.

Aerosol characteristics



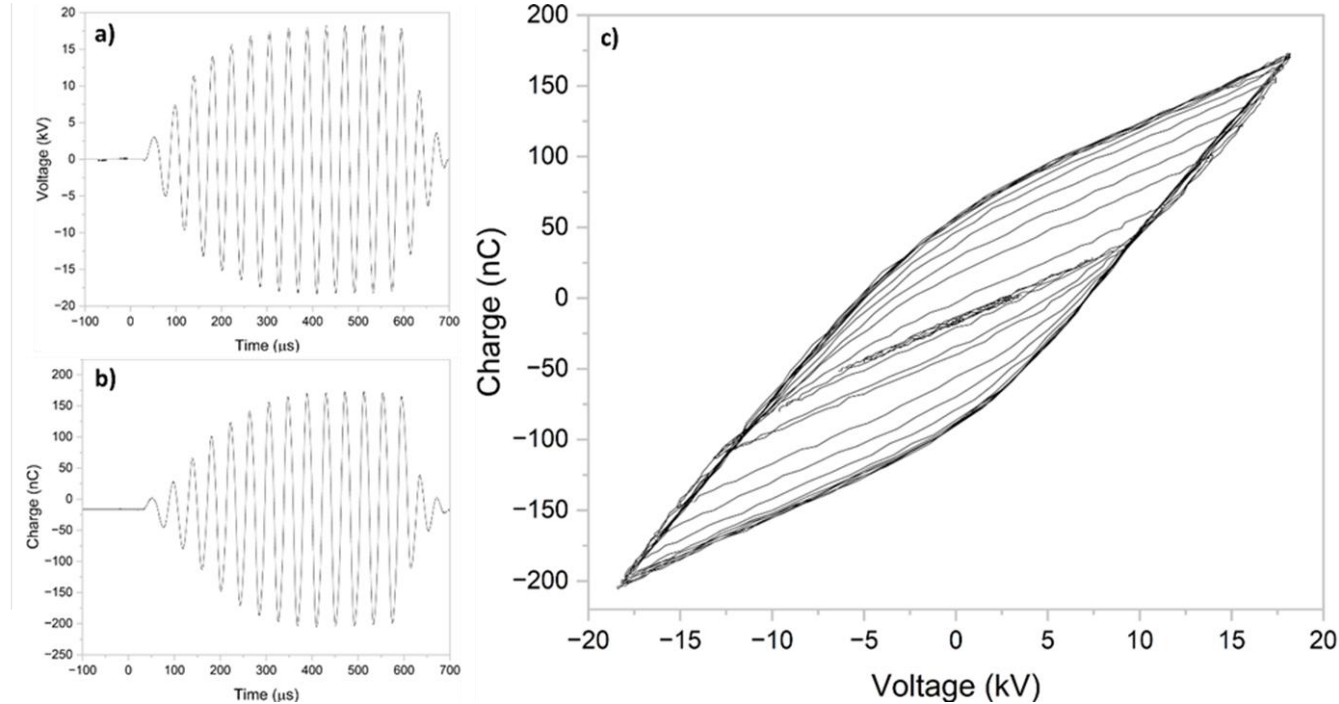
< 5 μm

aerosol droplet
diameter



After gas expansion and nebulization the fog reaches the substrate at $\sim 17^\circ\text{C}$ $\rightarrow$ products are not thermally stressed.

Electrical characteristics of the discharge



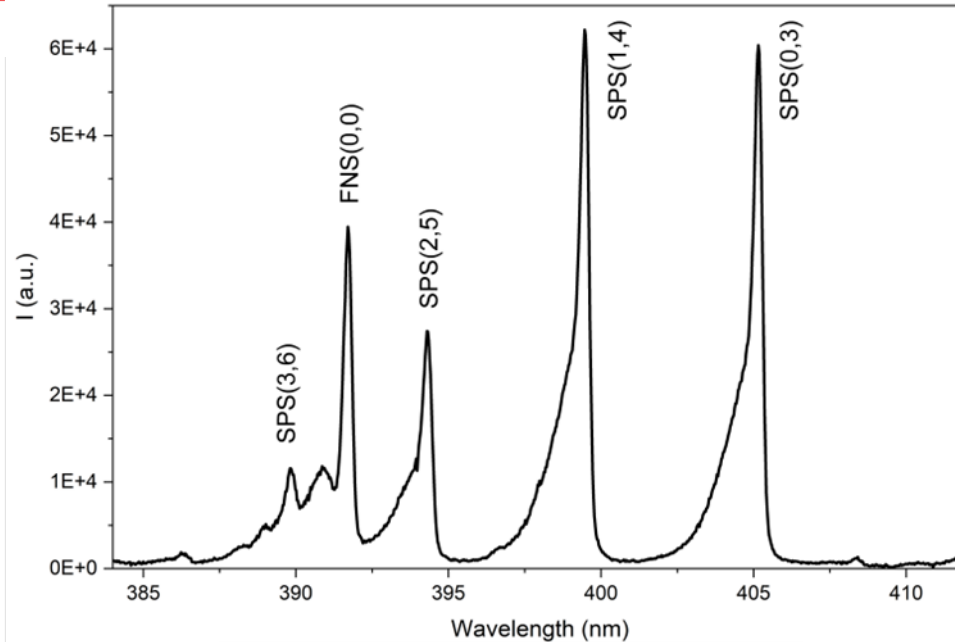
38 mJ

dissipated per
voltage burst

Almost ideal shape of the
Lissajous figure indicates a
regular, reproducible
discharge

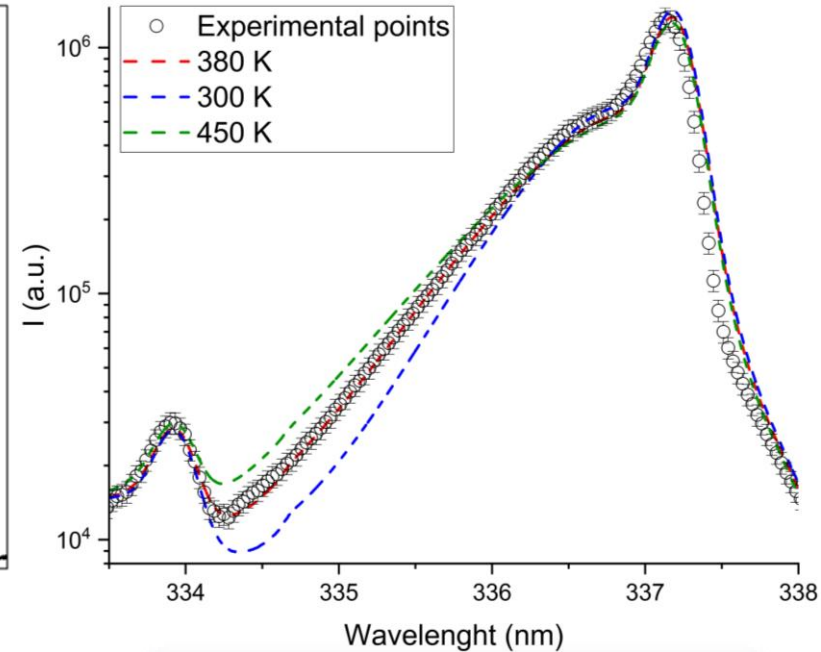


Optical Emission Spectroscopy



E/N from line ratios

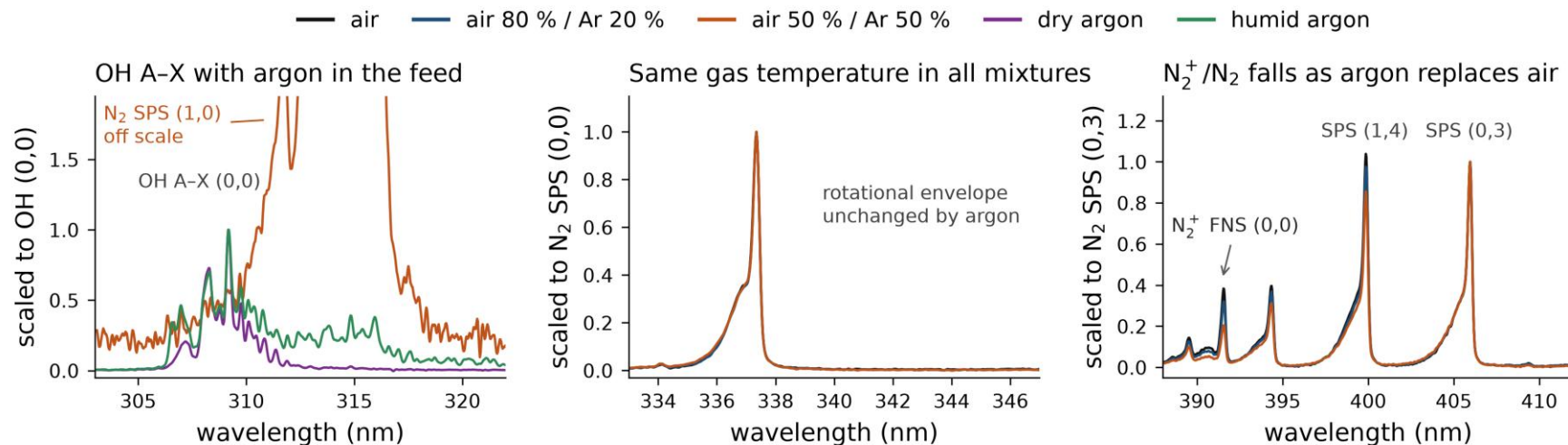
FNS 391.4 / SPS 337.1 nm intensity ratio: an E/N proxy in air.



Gas temperature

SPS(0,0) rotational structure: streamer gas temperature $\approx 107^\circ\text{C}$.

Emission spectra across feed-gas mixtures



Closed reactor, burst-averaged spectra, each panel scaled to the named band.

FNS/SPS falls

0.23 → 0.19 → 0.13 with argon; Ar* → N₂(C) transfer also lowers it.

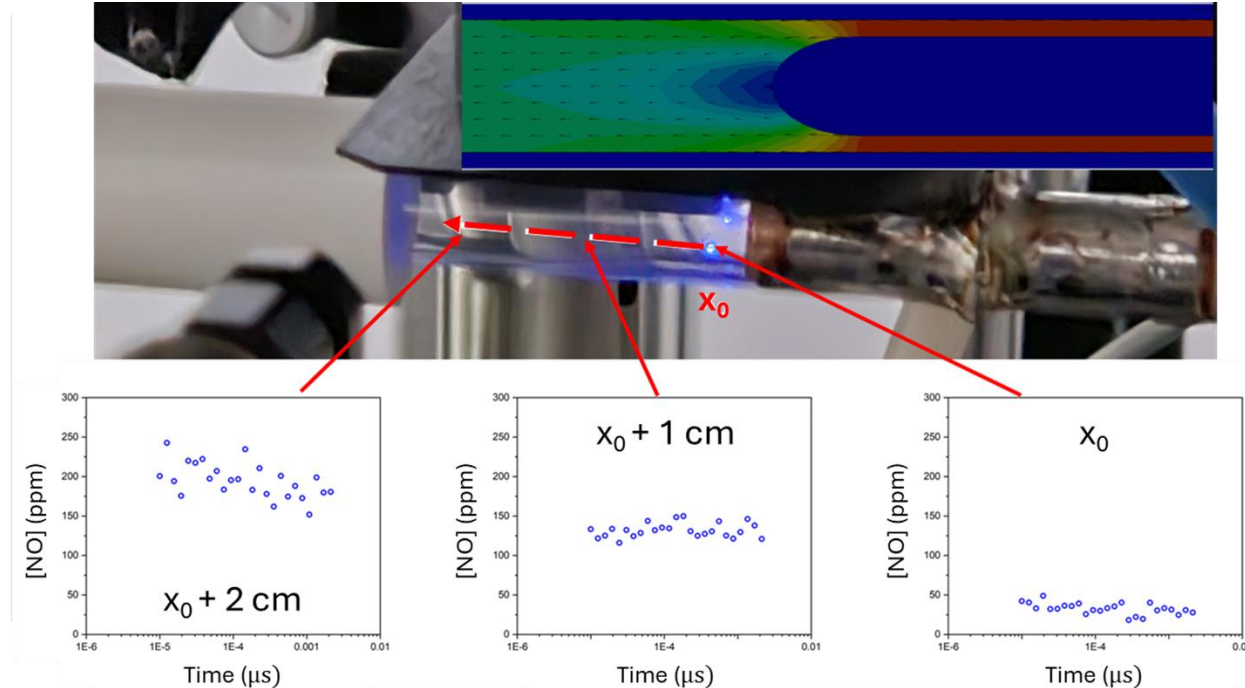
N₂ vibration drops

SPS (1,4)/(0,3): 1.01 → 0.95 → 0.84, a proxy of weaker N₂(v).

Same gas temperature

N₂(0,0) rotational envelope identical in the three air–argon mixtures.

RONS transport in the afterglow

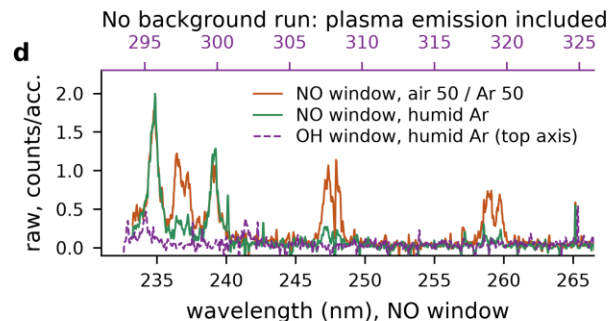
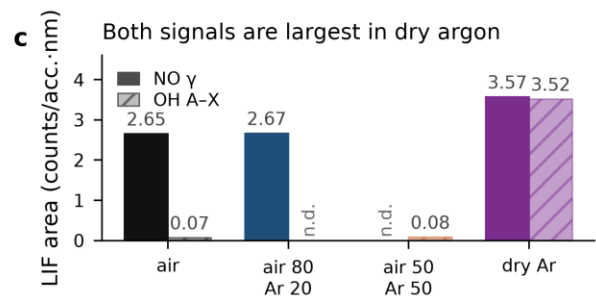
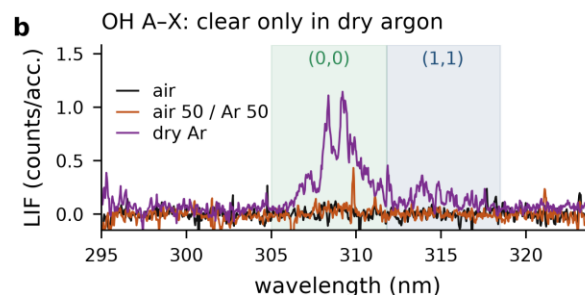
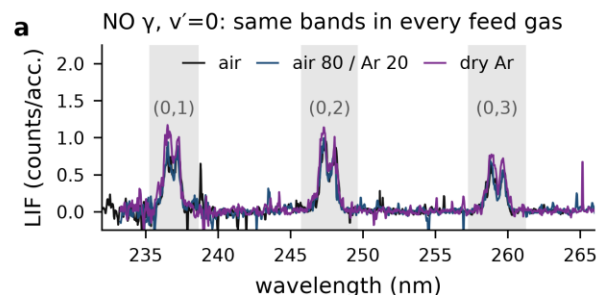


Transport + conversion

NO rises along the afterglow. x_0 lies in the recirculation just after the discharge. Downstream stations span 2-3 ms after the discharge zone.

ICCD LIF in the open tube, along the axis downstream of the discharge; inset: CFD gas-density map.

NO and OH fluorescence in the effluent



NO even in argon

NO $\gamma v'=0$ clean in air, 80/20 and dry argon: ambient air is entrained.

OH marks the plasma

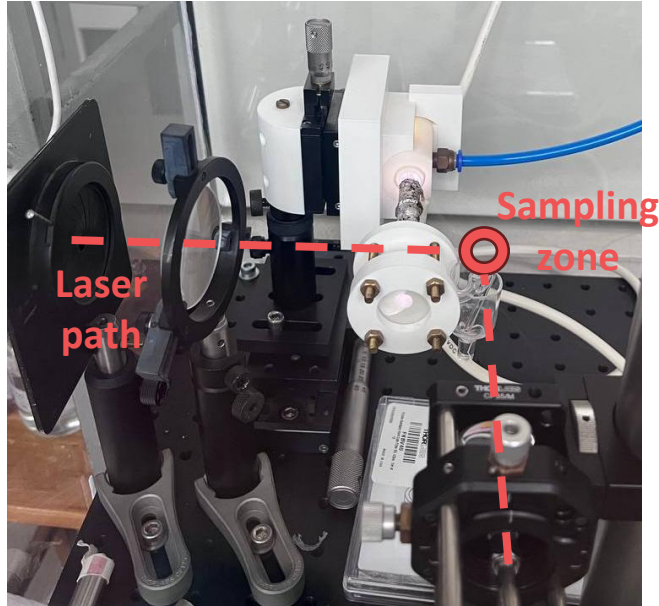
Strong in the discharge; marginal downstream, except in dry argon.

Yield, not density

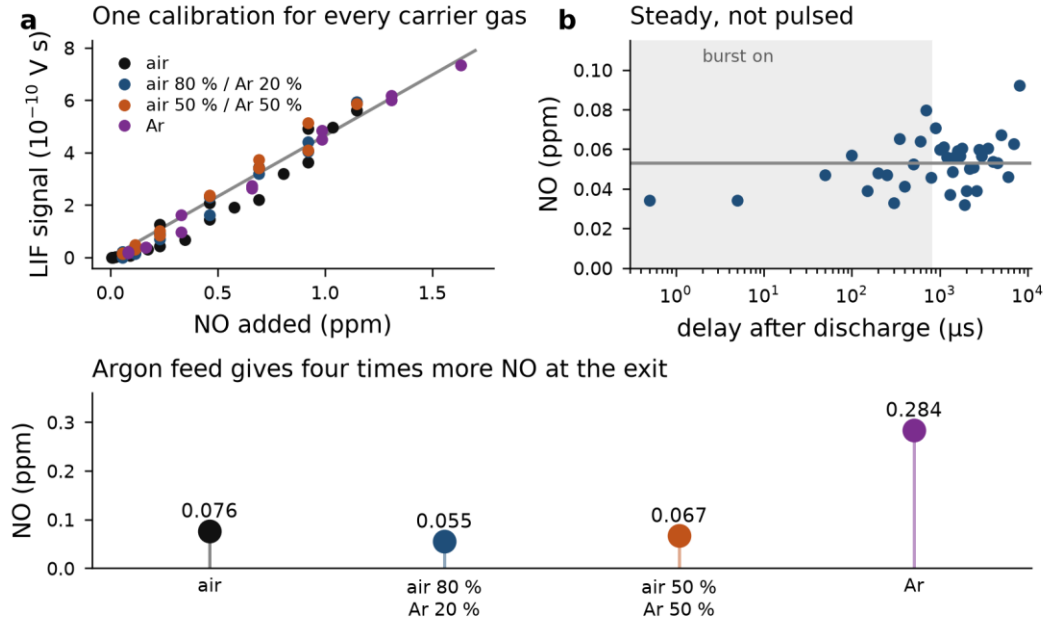
Quenching by N_2 , O_2 and H_2O is far stronger than by argon.

Background-subtracted LIF downstream of the open reactor

Absolute NO at the nozzle exit

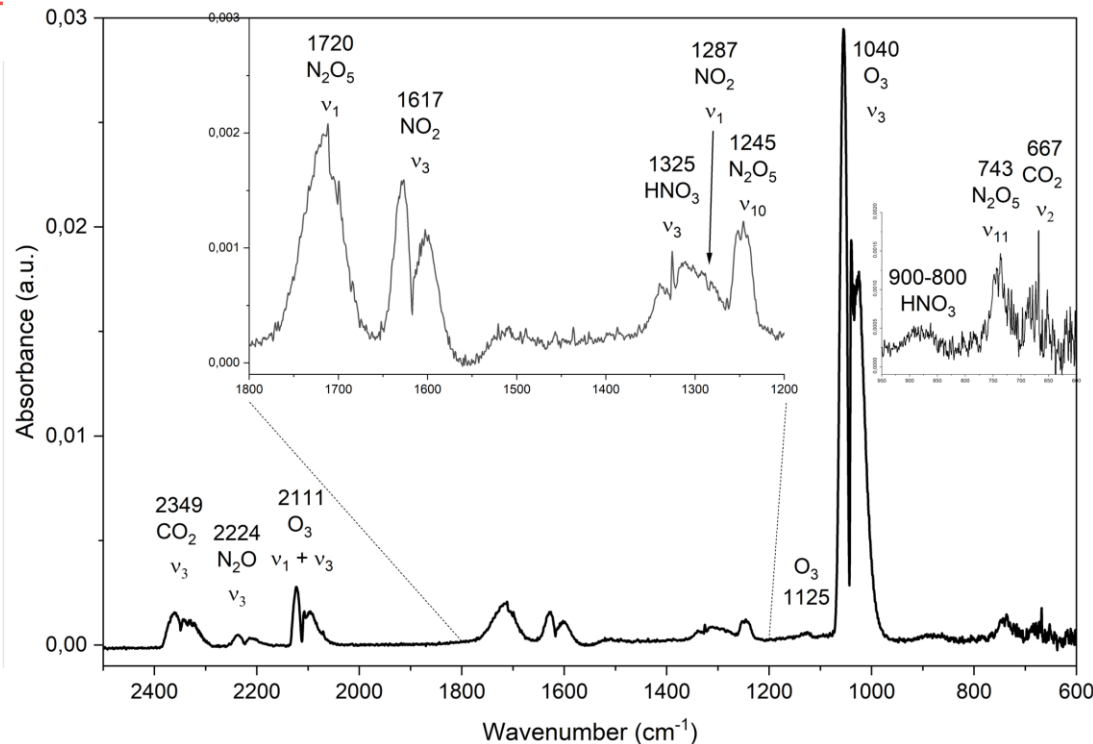


Collection with
optical fiber to
monochromator

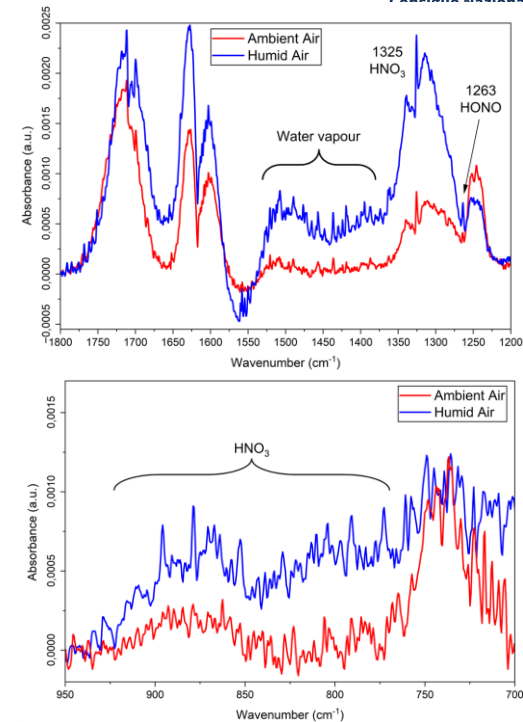


LIF at 226.16 nm, closed configuration, discharge-off background subtracted.

Long-lived RONS in the effluent



FT-IR of effluent gases: N₂O, NO₂, HNO₃, N₂O₅, O₃, CO₂

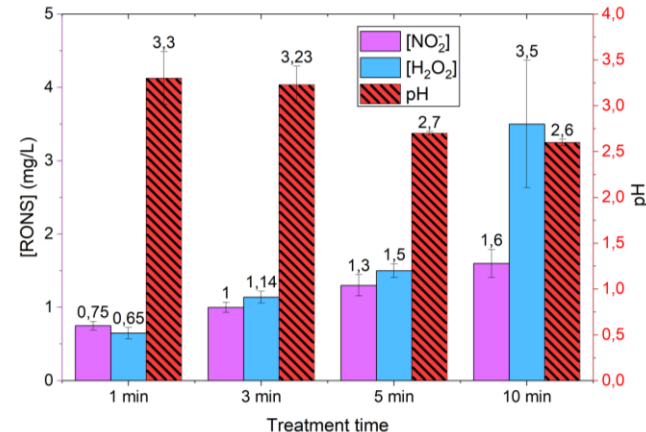
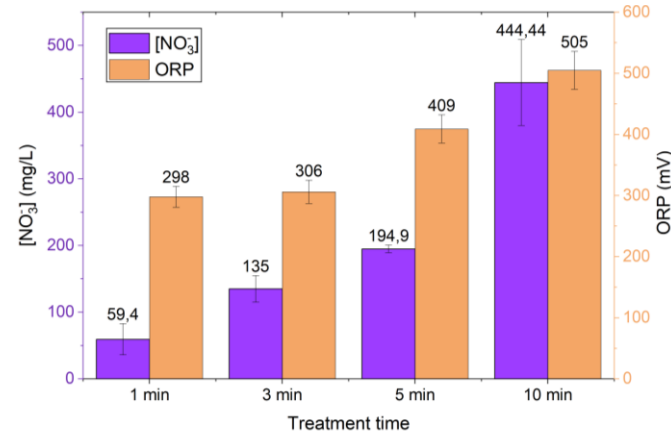


Ambient vs humid feed: adding water vapour to the plasma feed enhances HNO₃ and other oxygenated nitrogen species relevant to PAF chemistry.

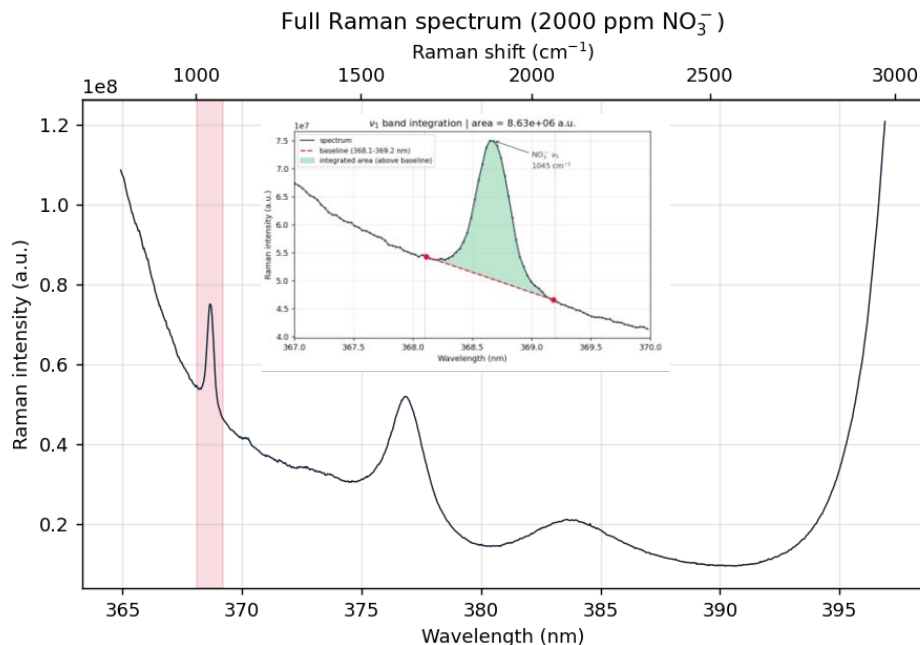
Condensed PAF composition

Time-dependent chemistry

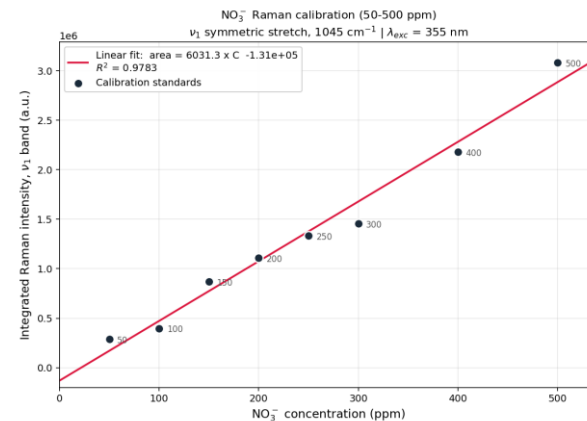
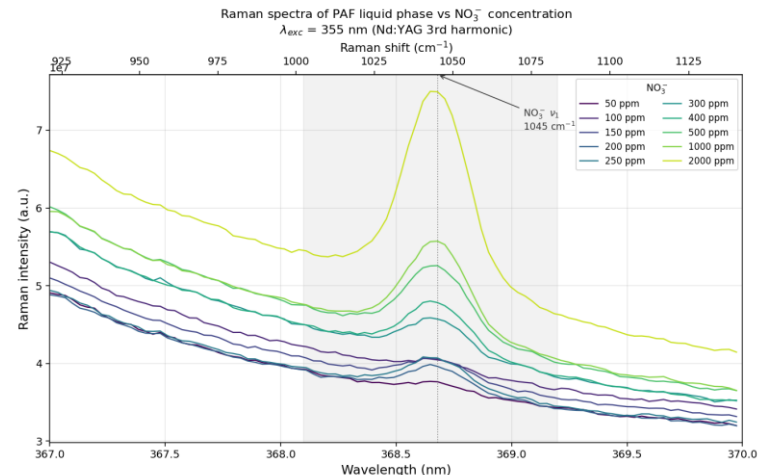
- NO_3^- becomes the dominant species:
~40 $\rightarrow$ 445 mg L^{-1} (1 $\rightarrow$ 10 min).
- H_2O_2 rises to 3.5 mg L^{-1} by 10 min; NO_2^- reaches 1.5 mg L^{-1} then plateaus.
- pH drops from 6 to 2.5, acidification tracks nitric-acid uptake.
- Condensation promotes gas-to-liquid uptake, favouring nitrate accumulation.
- H_2O_2 , NO_2^- , NO_3^- and acidic pH drive antimicrobial oxidative stress.



Raman Spectroscopy

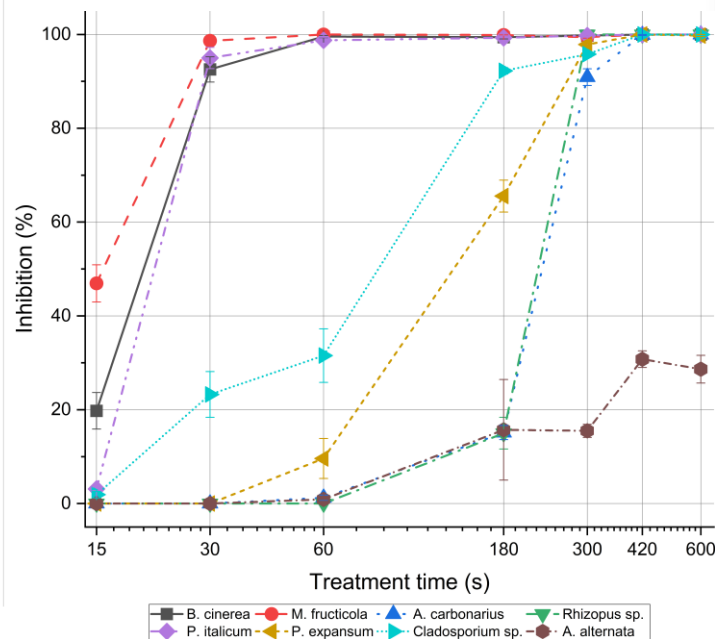


The nitrate v_1 symmetric-stretch band (1045 cm^{-1}) gives a label-free measure of $[\text{NO}_3^-]$



From reactive chemistry to decontamination – *in vitro*

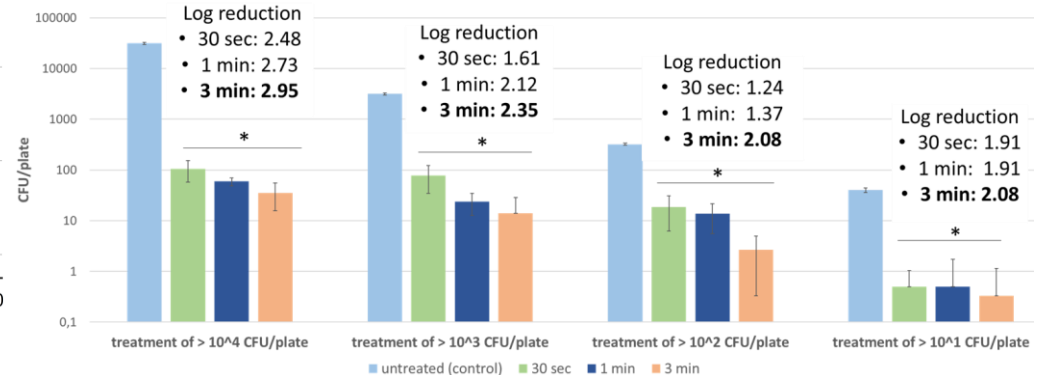
Conidial germination inhibition



Post-harvest fungi

Complete spore inhibition after 3–5 min for most species; *M. fructicola* most sensitive, *A. alternata* / *A. carbonarius* most resistant.

Listeria monocytogenes (five-strain mix): all conditions ($p < 0.05$)



≤ 30 s

for marked in-vitro CFU drop

From reactive chemistry to decontamination – *in vivo*



52–74 %

fewer rotted strawberries



Untreated



Treated (10 min)

Strawberries & table grapes — untreated vs. 10 min PAF

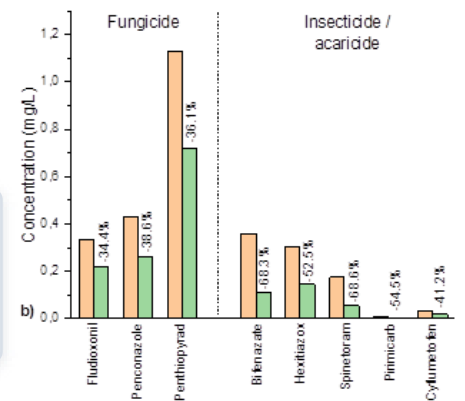
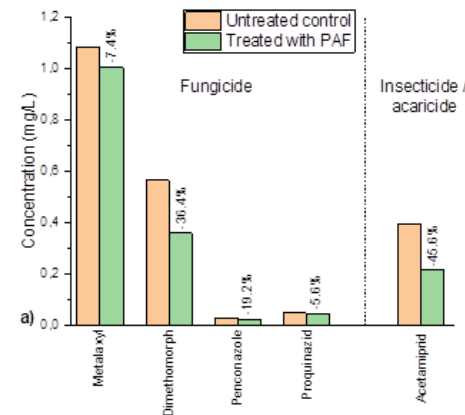
45–80 %

fewer rotted table grapes
(cultivar-dependent)

up to 70 %

reduction of chemical
pesticides

Pesticide residues: untreated vs. PAF



An integrated diagnostic path for plasma agriculture

- One diagnostic path follows RONS from the discharge field to the treated liquid.
- **Discharge physics.** 38 mJ/burst heats the gas to ≈ 380 K, OES identifies reactive species and gives E/N trends.
- **Gas phase.** Calibrated LIF gives absolute NO, OH marks the active zone, FT-IR tracks NO_x , HNO_3 and O_3 .
- **Liquid phase.** Raman, validated by colorimetry, quantifies NO_3^- , NO_2^- and H_2O_2 as the PAF acidifies.
- Linking operating conditions to RONS dose underpins scale-up and predictive treatments.

Next steps

- E/N in all gas mixtures
- $\text{N}_2(\text{v})$ kinetics and Zel'dovich NO
- Dose-response optimisation
- Pre-industrial post-harvest trials

THANK YOU FOR YOUR ATTENTION!

