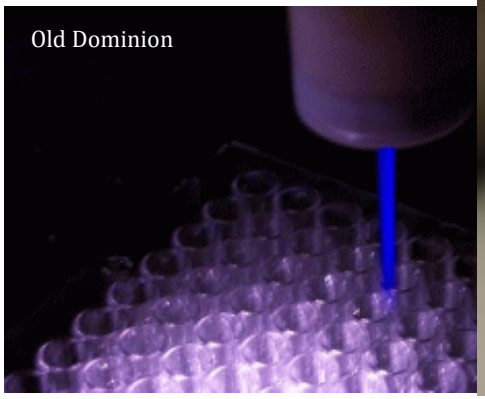
# Project 3

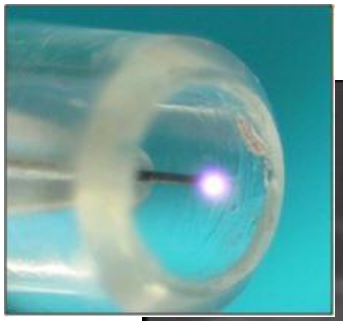
- **Title:** Planar plasma jet: characterization, diagnostics and surface interaction
- **PI:** Danil Dobrynin, Drexel University
- **Need and Relevance:** planar He jet characterization for future applications (surface treatment, plasma medicine)
- **Goals:** to understand planar He plasma jet development and its characterization
- **Approach:** characterization of uniformity, measurements of plasma parameters and chemicals in gas and liquid phases
- **Outcomes/Deliverables:** data on planar jet development, propagation and chemical characteristics
- **Project Duration, Budget: 3** years, $120k

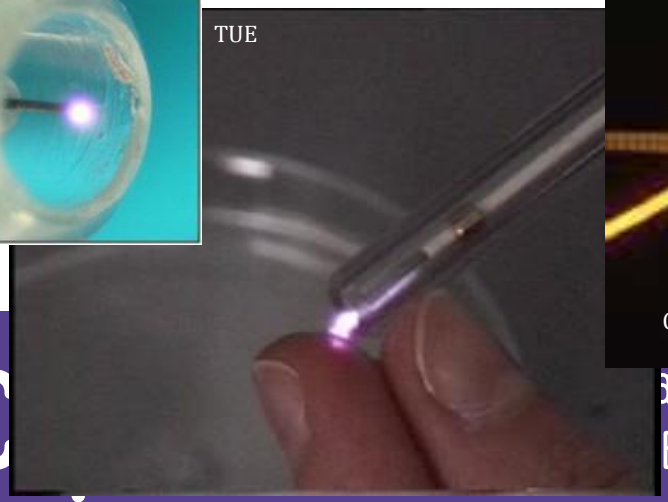
# Plasma jets for surface treatment/medicine

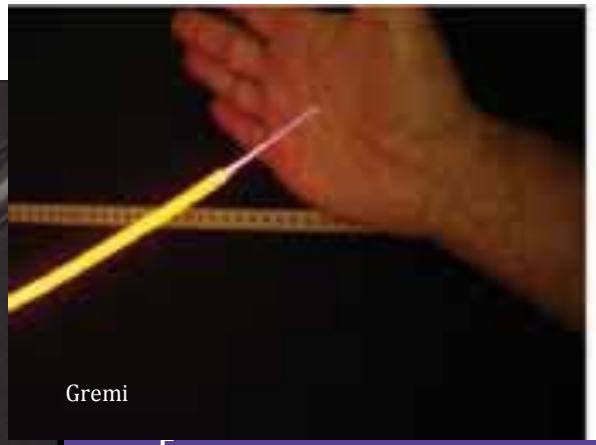




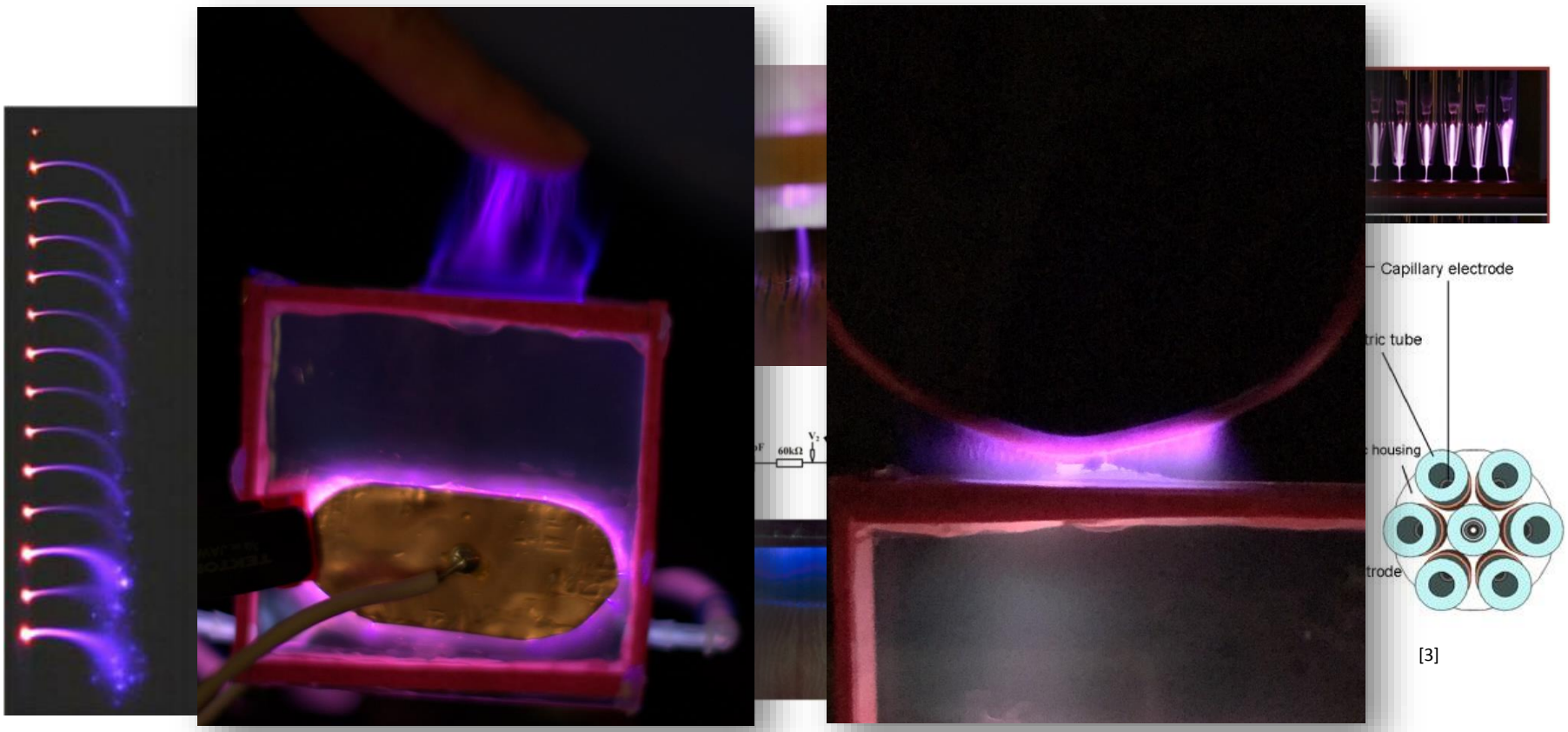






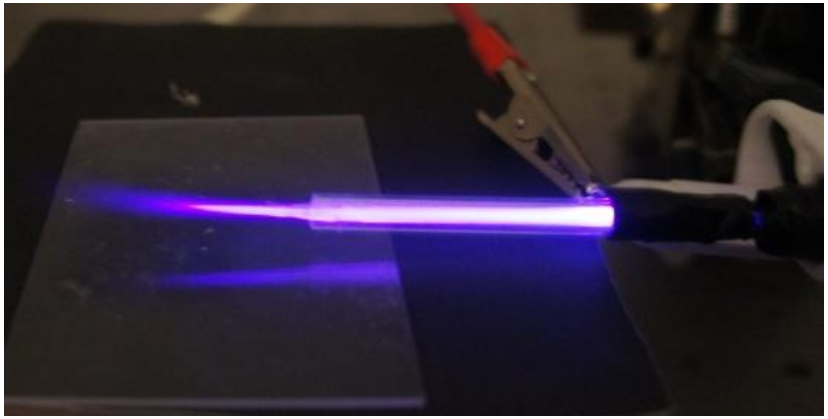

# Multi-jets, arrays, ”brushes” for large surface treatment

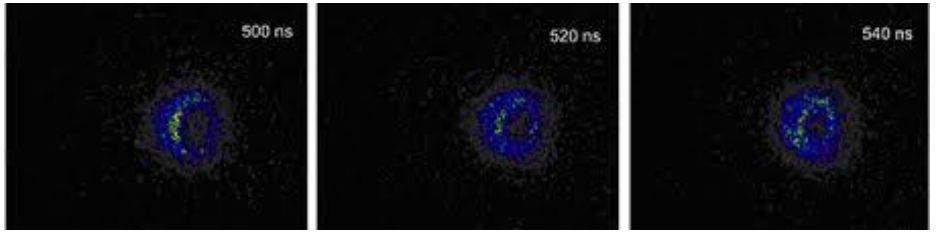





[1] J.U. Neuber, S. Song, M.A. Malik, L. Heller and C. Jiang, "Nanosecond Pulsed Plasma Brush for Bacterial Inactivation on Laminate," in IEEE Transactions on Radiation and Plasma Medical Sciences, vol. 1, no. 4, pp. 368-373
[2] Kim, Sun Ja, Tae Hun Chung, Hea Min Joh, Ju-Hong Cha, In Sub Eom and Ho Jun Lee. "Characteristics of Multiple Plasma Plumes and Formation of Bullets from Atmospheric-Pressure Plasma Jet Array." IEEE Transactions on Plasma Science 43 (2015): 753-759.
[3] QY Nie et al 2009 New J. Phys. 11 115015
[4] X Lu et al 2011 Plasma Sources Sci. Technol. 20 065009

# Plasma “bullets” – what are they?



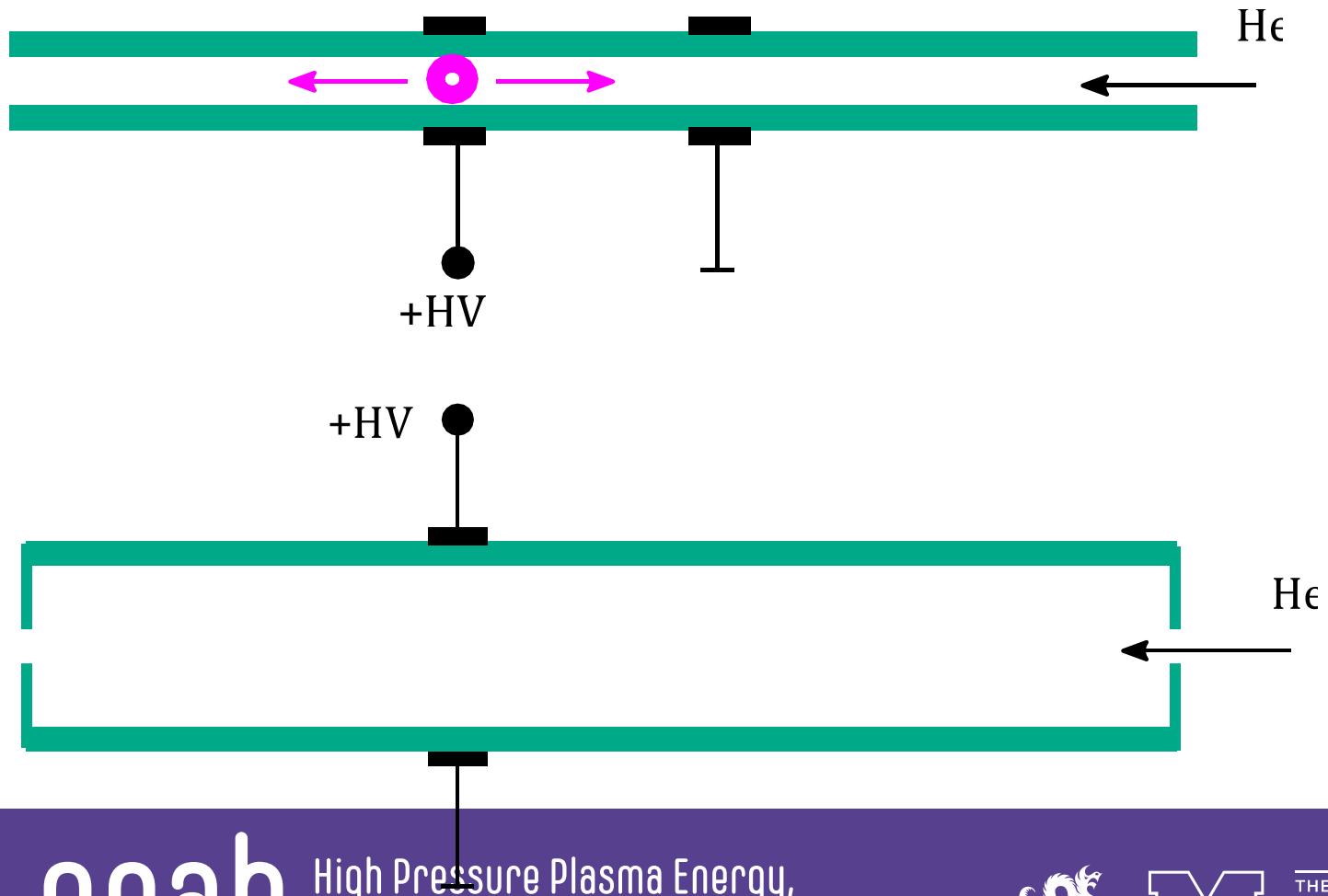



Xian Y, Lu X, Cao Y, Yang P, Xiong Q, Jiang Z and Pan Y 2009 IEEE Trans. Plasma Sci. 37 2068


J-P Boeuf et al 2013 J. Phys. D: Appl. Phys. 46 015201

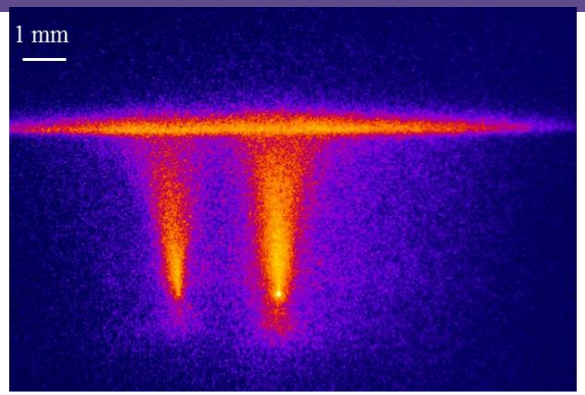
- Propagating surface ionization wave ➔ donut shape

# DBD-based plasma jet

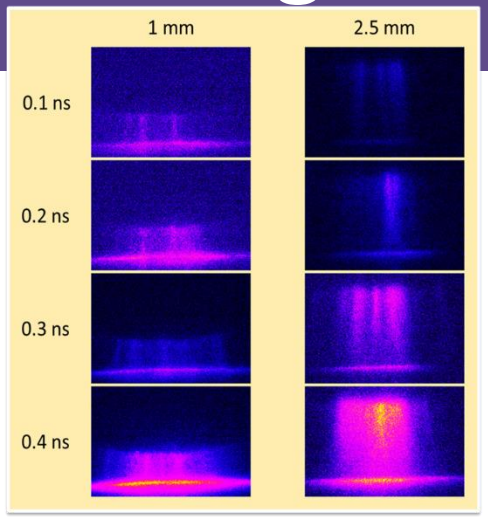


# DBD and plasma jet – initiation stage 1

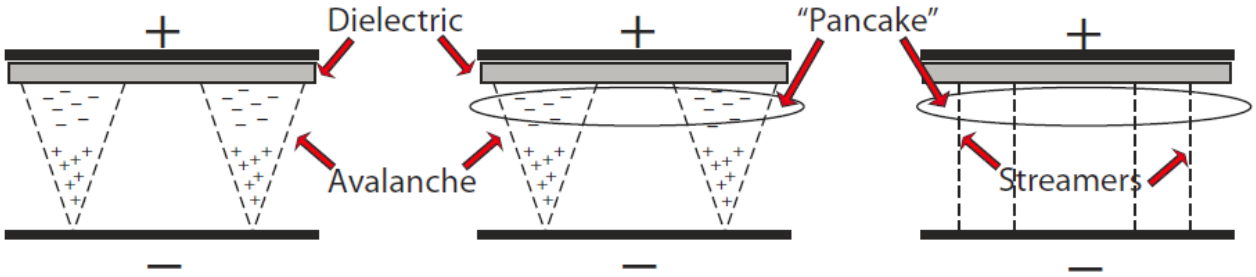
Evolution of pulsed DBD starts with formation of transient anode glow, and only then continues with development of cathode-directed streamers

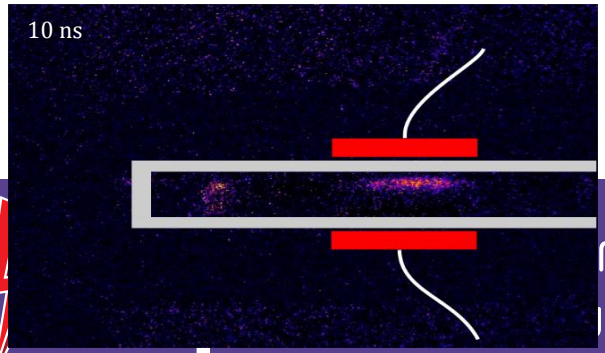


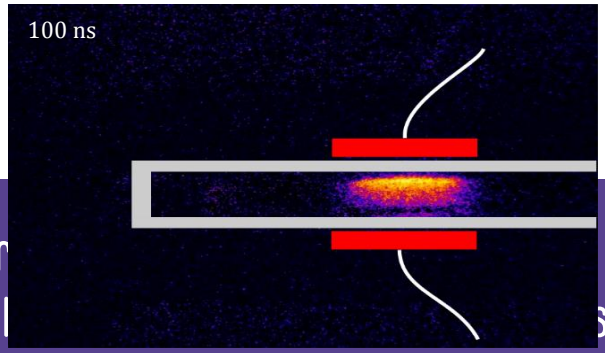

62 kV/cm

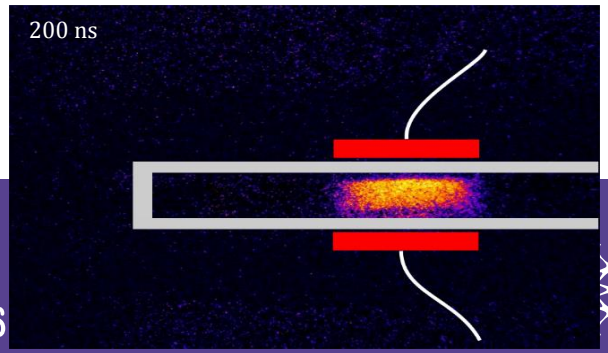



200 ps exposure, 100 accumulations

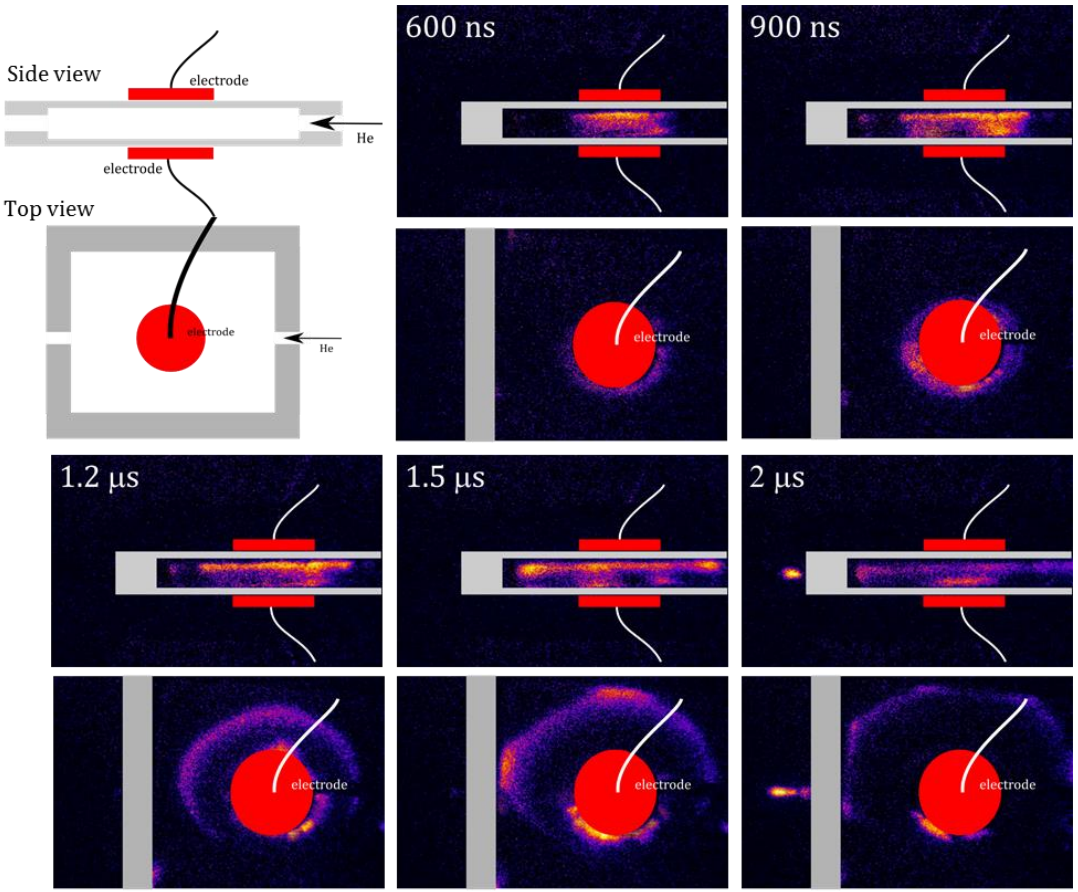


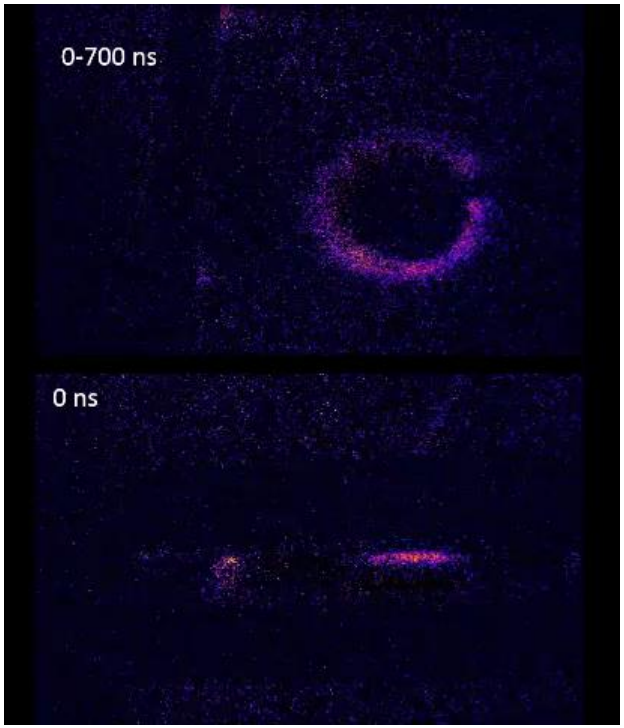



# Stage 2 - Surface wave propagation

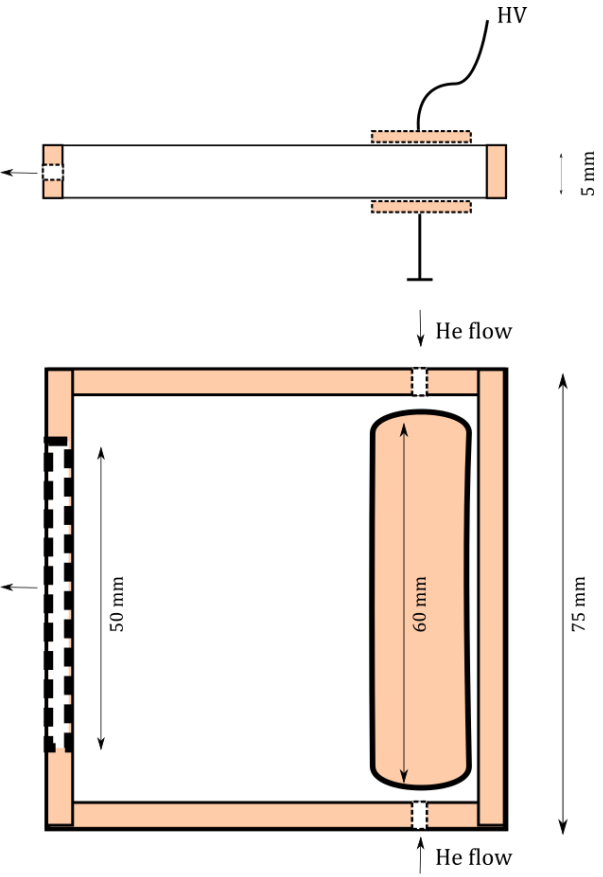


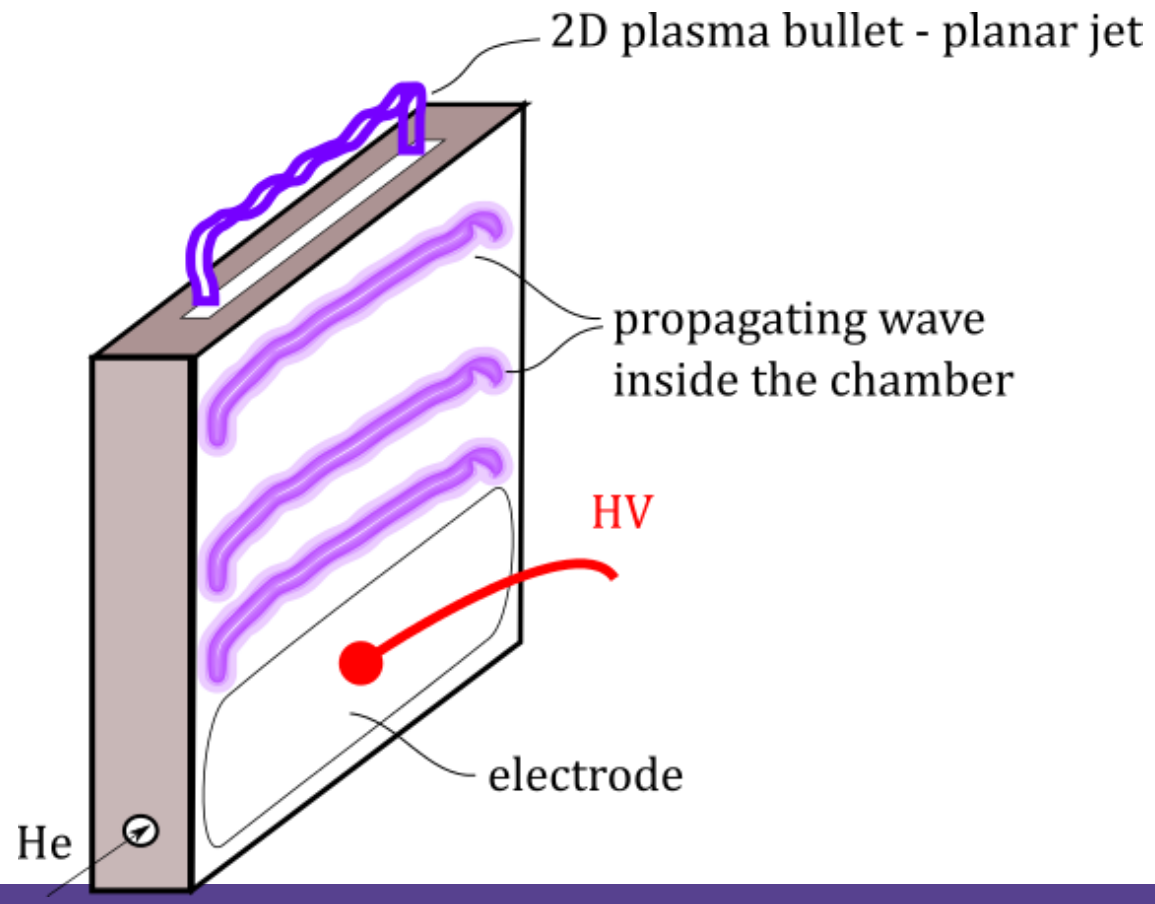

~30 km/s




In noble gases, the anode glow can propagate as ionization wave along the dielectric surface outside of the discharge gap. For the case of traditional dielectric tubes, the ionization wave appears as what is known as a “plasma bullets”, often with characteristic “donut” shape

# Planar He DBD plasma jet

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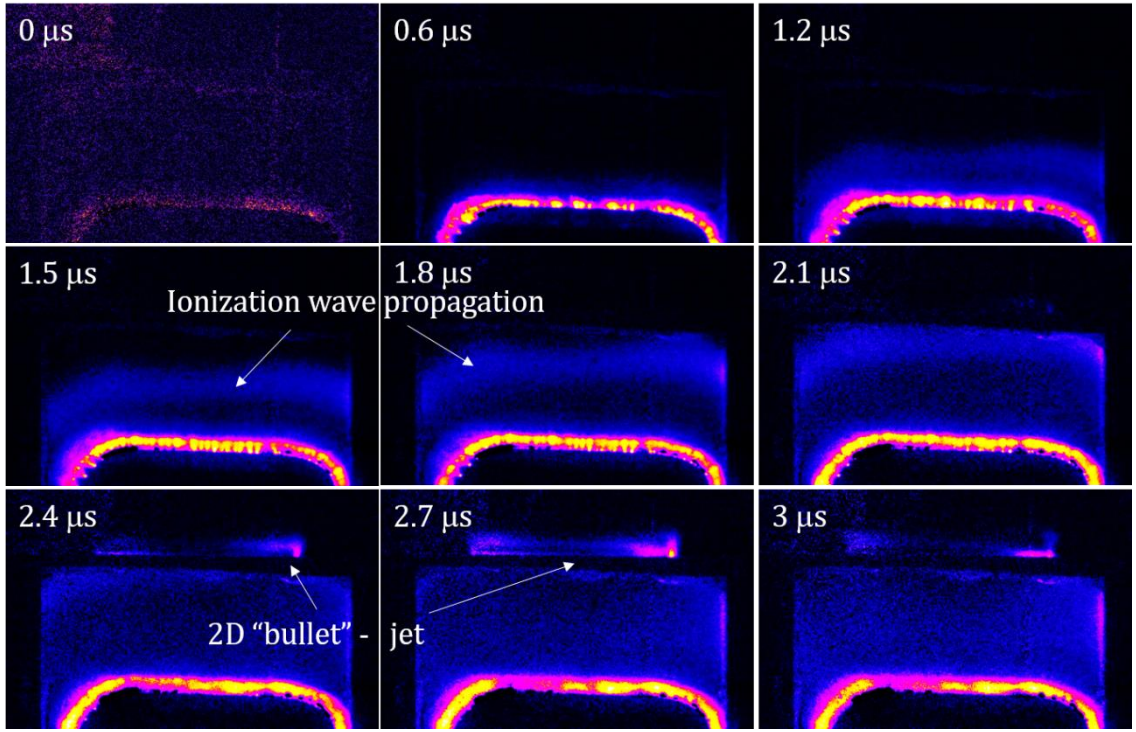
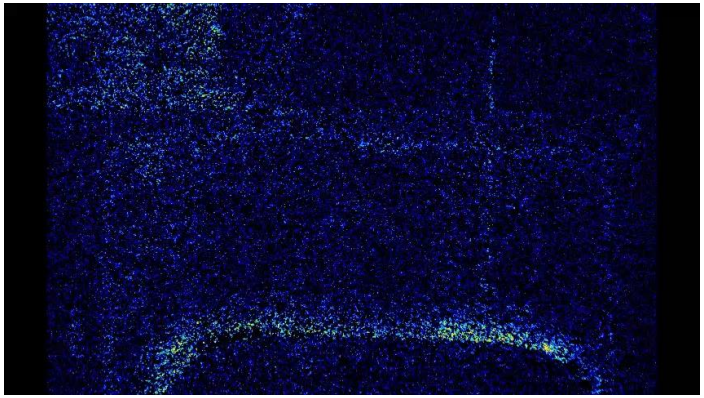
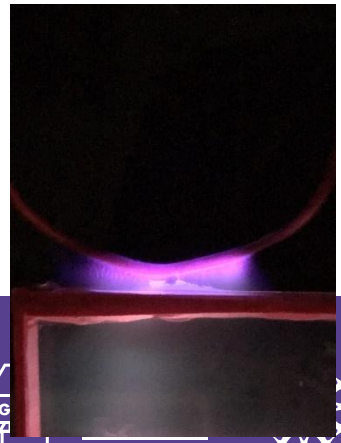
High Pressure Plasma Energy, Agriculture, and Biomedical Technologies

Drexel MICHIGAN THE GEORGE WASHINGTON UNIVERSITY WASHINGTON, DC nsf

# Planar He DBD plasma jet

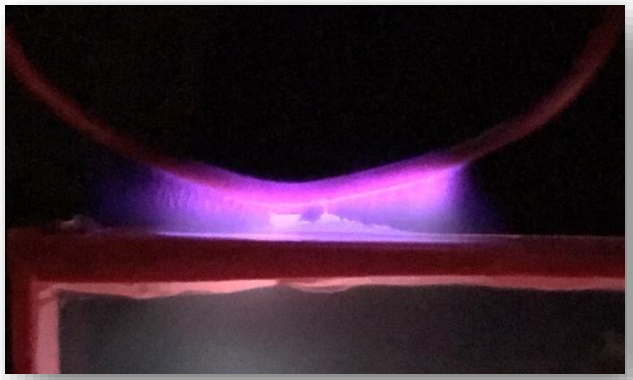




# Need and Industrial Relevance

- Uniform plasma treatment with controllable parameters



**Materials and Manufacturing**

- E.g., Plasma deposition
- Plasma etching
- Surface treatment

**Plasma Medicine**

# Project Goals

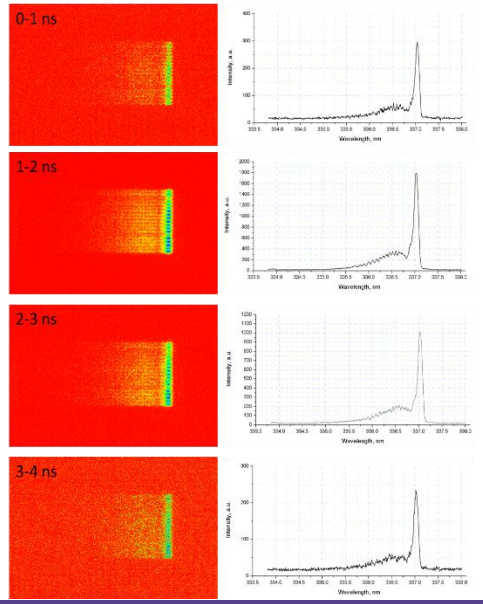
- **The goal of the proposed efforts** is to carry out a fundamental study of the planar DBD-based plasma jet, and especially to understand physical mechanisms of jet formation via measurements of electric fields, jet attachment and interaction with the treated surface and to measure reactive chemistry (e.g., gas phase OH and liquid phase $H_2O_2$)

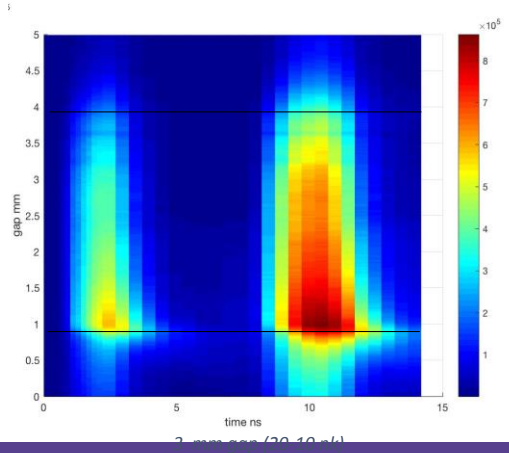
# Objectives

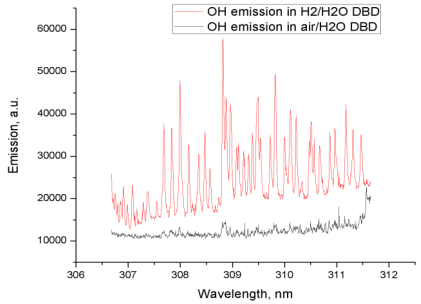
- **Quantitative characterization of planar He plasma jet uniformity and reactive chemistry**
  - imaging of the discharge dynamics and development and quantification of plasma uniformity
  - measurements of electric fields inside the plasma chamber, during propagation and at the treated surface
  - spatially resolved spectroscopy to determine plasma characteristics (temperature)
  - spatially resolved measurements of OH generation in gas phase and its delivery into liquid ($H_2O_2$)

# Approach/Methods

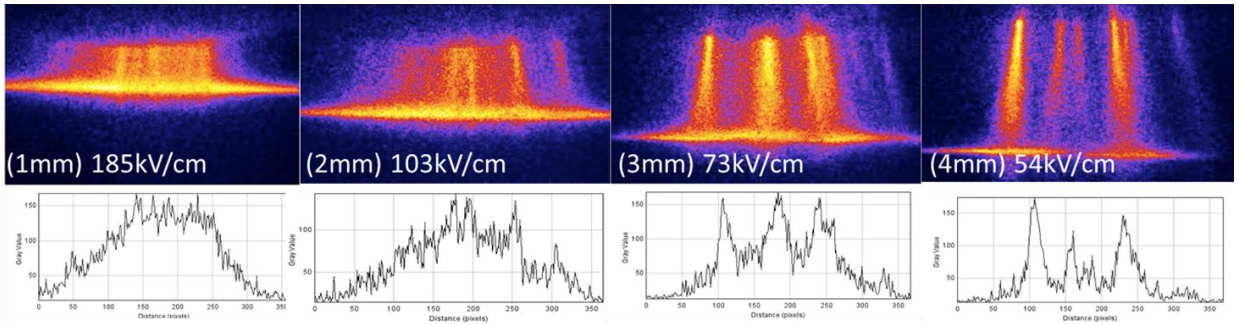

- **Fast imaging**
- **Optical emission spectroscopy**
- **Absorption spectroscopy**
- **Fluorescence spectroscopy**



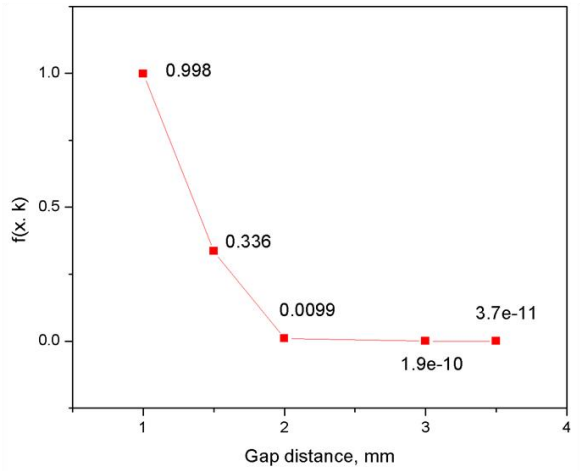



# Task 1: quantification of uniformity

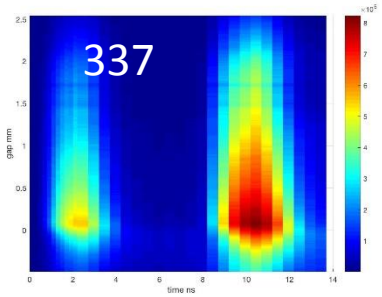


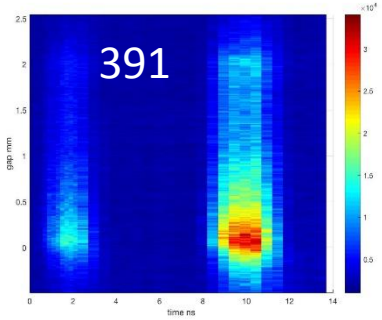

Chi-Square test: distribution of "brighter" pixels as measure of uniformity

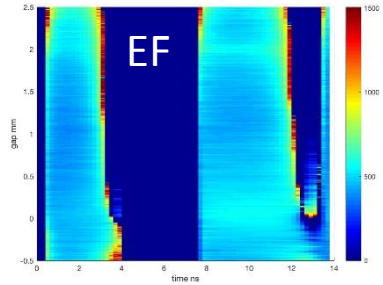
$$f(x,k) = \begin{cases} \dfrac{x^{(k/2)-1}e^{-x/2}}{2^{k/2}\,\Gamma\left(\frac{k}{2}\right)}, x \geq 0; \\ 0, otherwise \end{cases}$$



# Task 2a: measurements of electric field



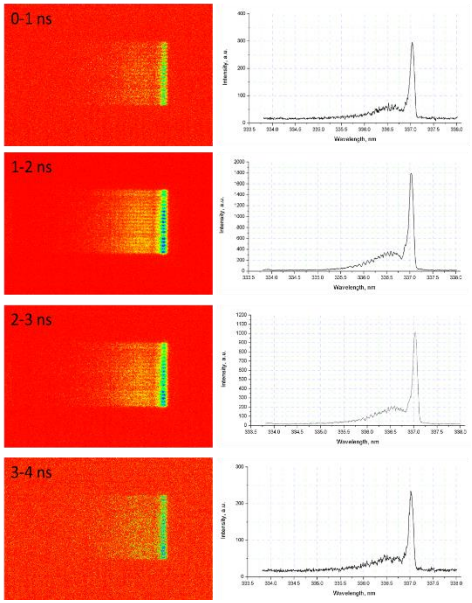





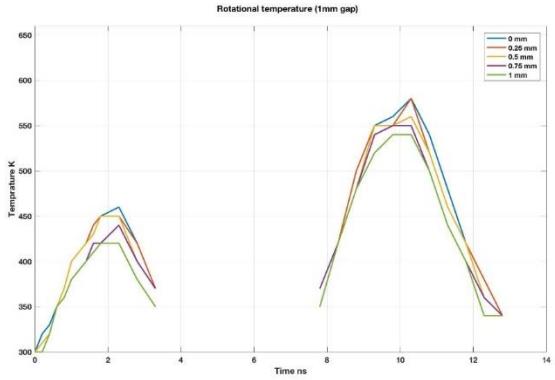
$$R_{391/337}\left(\frac{E}{N}\right) = 46 \cdot A \cdot \exp\left[-89\left(\frac{E}{N}\right)^{-0.5}\right] \cdot 0.065 \exp\left[-402\left(\frac{E}{N}\right)^{-1.5}\right]$$

$$\frac{\frac{dI(t)_{391}}{dt} + \frac{I(t)_{391}}{\tau_{391}}}{\frac{dI(t)_{337}}{dt} + \frac{I(t)_{337}}{\tau_{337}}} \cdot \frac{\tau_{391}}{\tau_{337}} = R_{391/337}$$

# Task 2b: temperature measurements



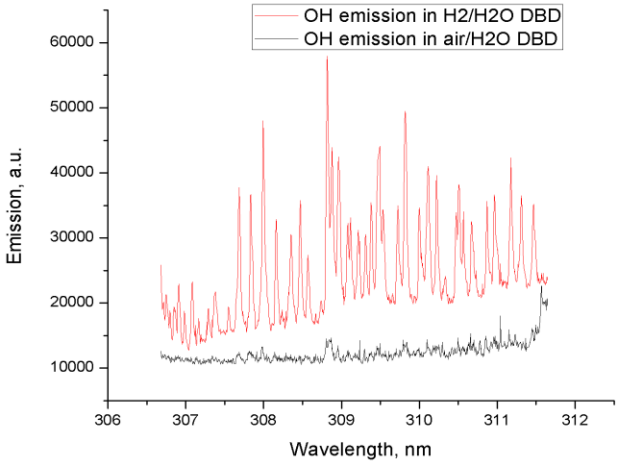




# Task 3a: measurements of OH

- Absorption spectroscopy

$$A(\lambda) = 1 - \frac{L_{plasma+LED}(\lambda) - L_{plasma}(\lambda)}{L_{LED}(\lambda) - L_{back}(\lambda)}.$$



# C-PEAB Project Proposal

- **Title:** Planar plasma jet: characterization, diagnostics and surface interaction
- **PI:** Danil Dobrynin, Drexel University
- **Need and Relevance:** planar He jet characterization for future applications (surface treatment, plasma medicine)
- **Goals:** to understand planar He plasma jet development and its characterization
- **Approach:** characterization of uniformity, measurements of plasma parameters and chemicals in gas and liquid phases
- **Outcomes/Deliverables:** data on planar jet development, propagation and chemical characteristics
- **Project Duration, Budget: 3** years, $120k

# Project Budget (per year)

| Item | Cost |
|---|---|
| Salaries/stipend | $ 35000.00 |
| Supplies | $ 5000.00 |
| Purchased services | $ 0.00 |
| Equipment | $ 0.00 |
| Travel | $ 0.00 |
| **Project total*** | **$ 40,000** |

*C-PEAB leadership recommends not to exceed $40,000/year unless discussed with IAB