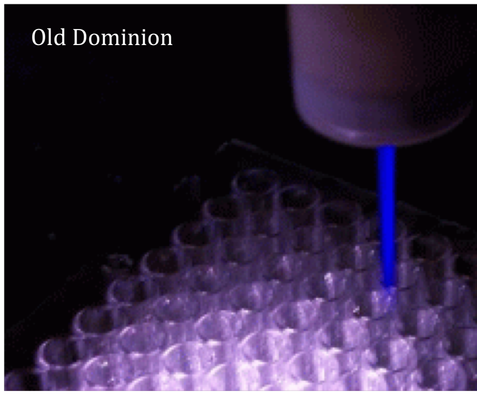
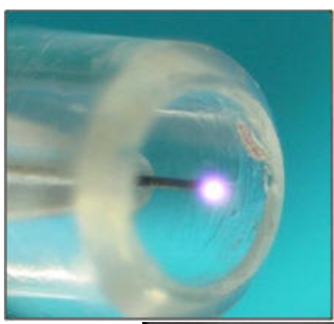
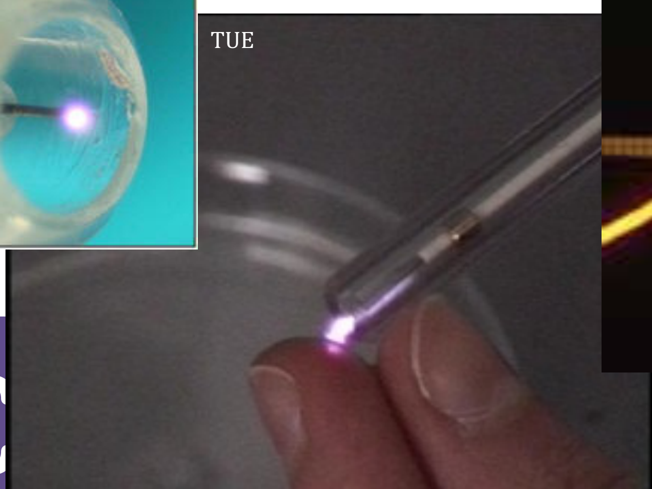
Project 3

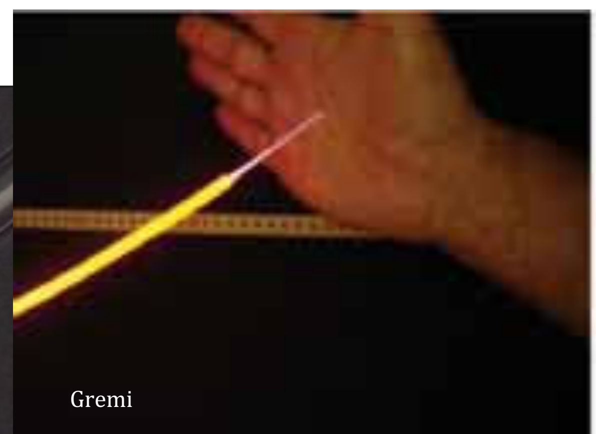
- **Title:** Planar plasma jet: characterization, diagnostics and surface interaction
- **PI:** Danil Dobrynin, Drexel University
- **Need and Relevance:** planar He jet characterization for future applications (surface treatment, plasma medicine); development of *in situ* diagnostics
- **Goals:** to understand planar He plasma jet development and its characterization; development of *in situ* diagnostics
- **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; development of *in situ* diagnostics
- **Project Duration, Budget: 3** years, $120k

Plasma jets for surface treatment/medicine

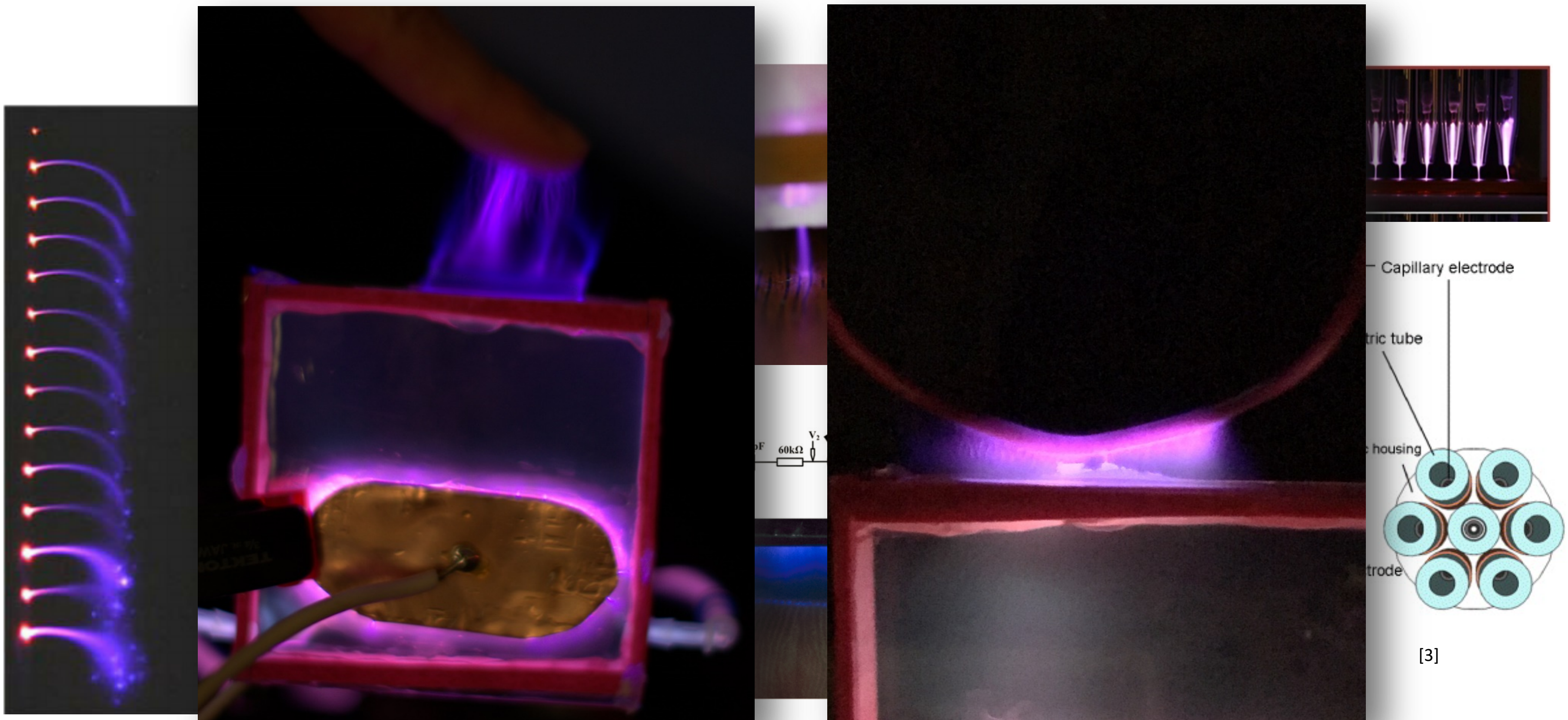








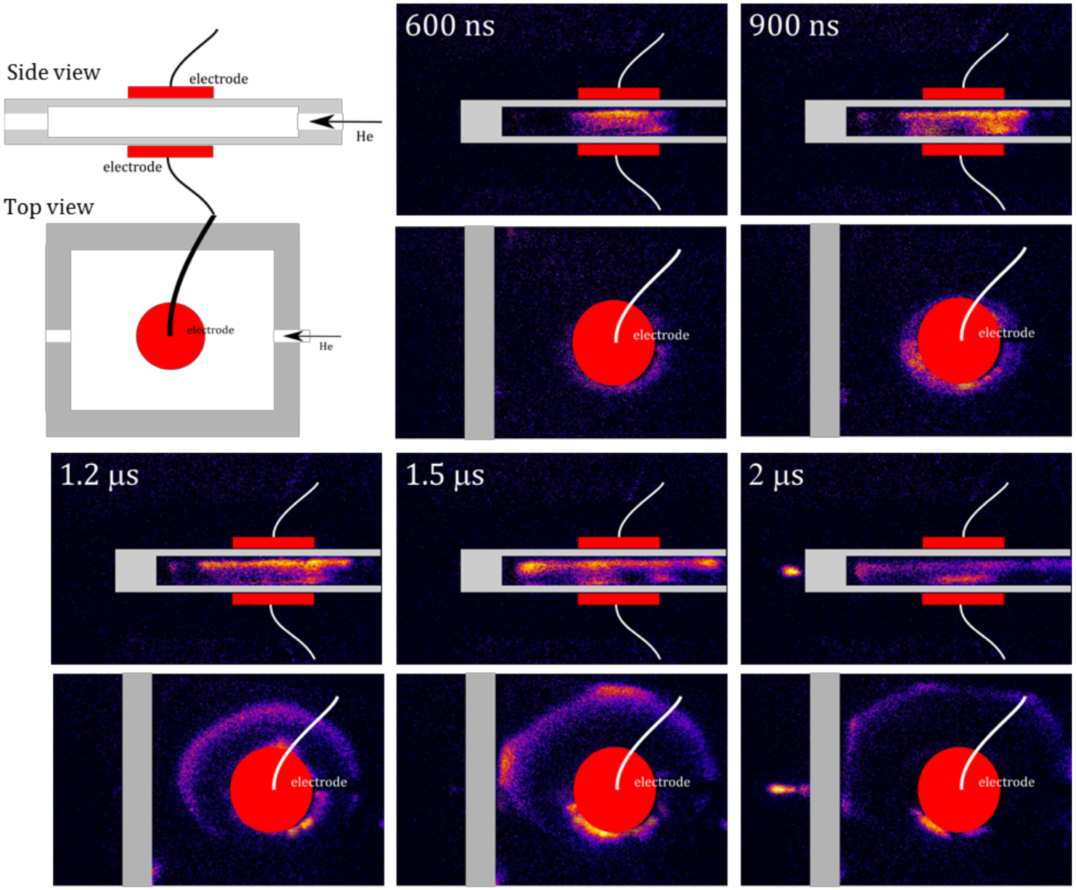
Multi-jets, arrays, ”brushes” for large surface treatment



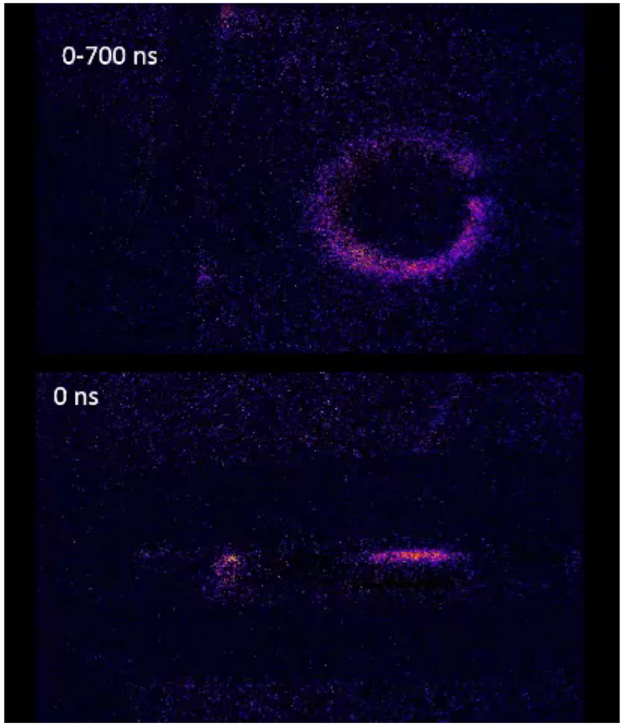
[3]

[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. 368-375
[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 in an 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

Surface wave propagation

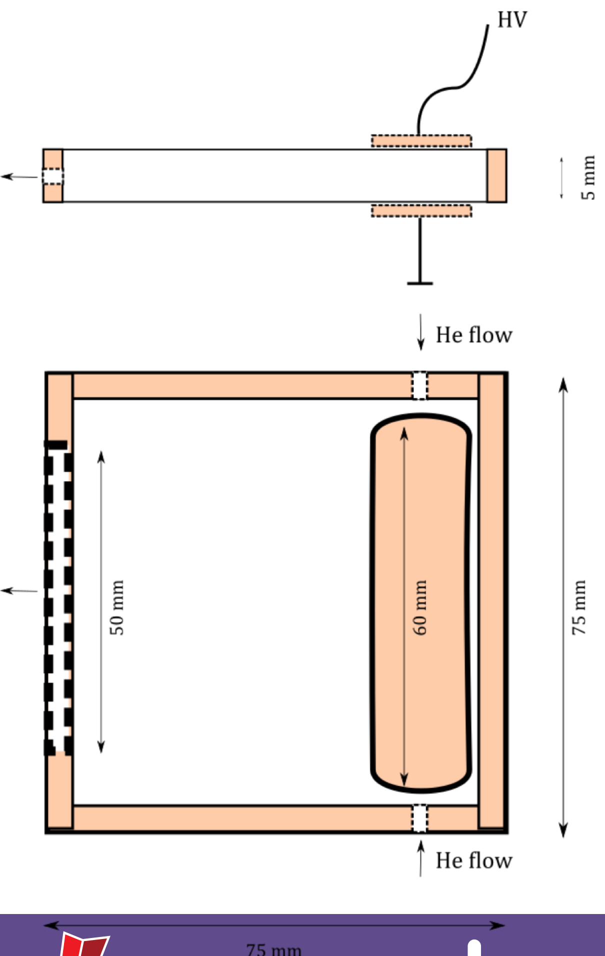


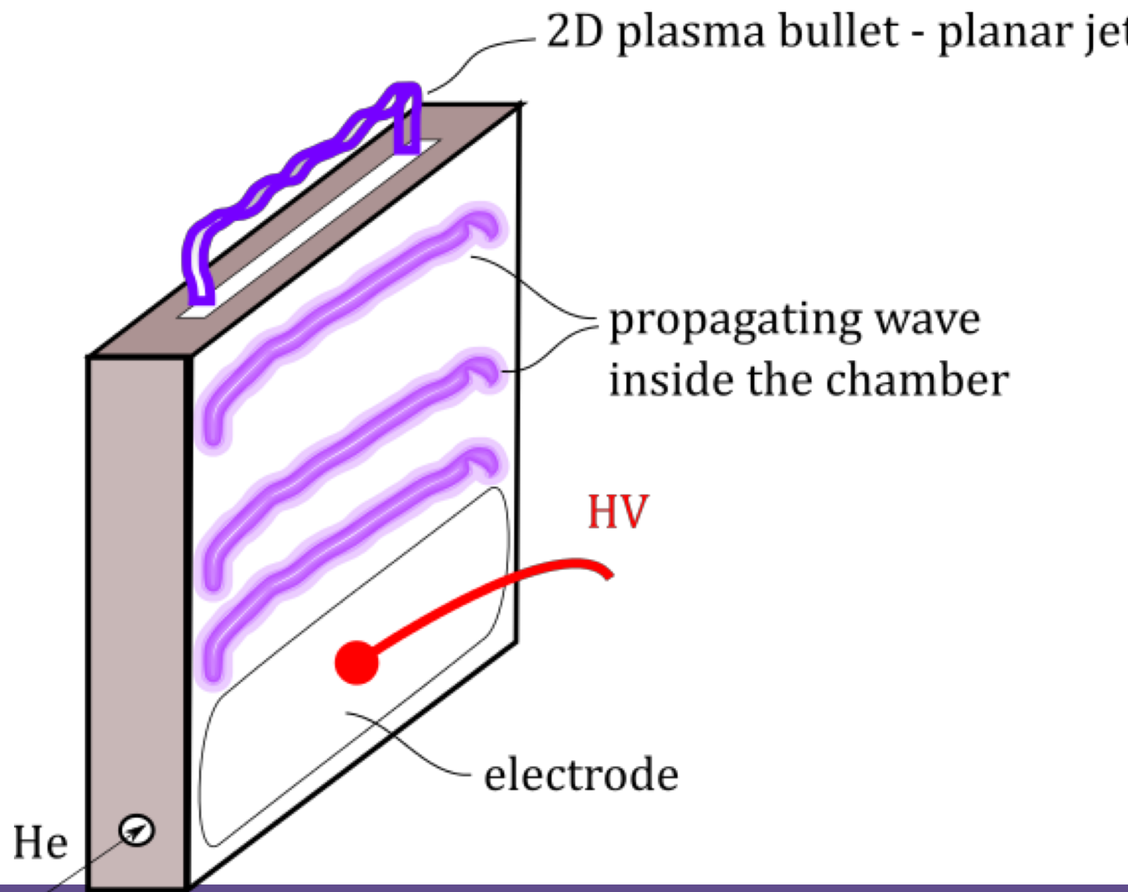
~30 km/s



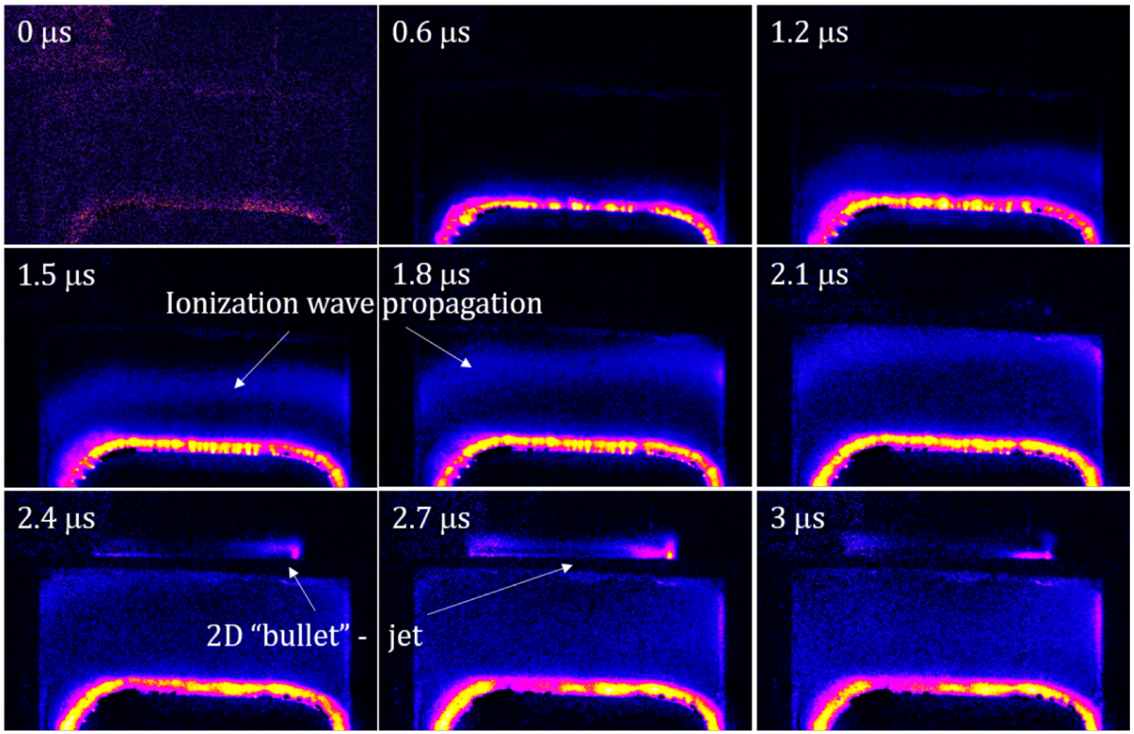
In noble gases, the anode glow can propagate as ionization wave along the dielectric surface outside of the discharge gap. For the case of traditional dielectric tubes, the ionization wave appears as what is known as a "plasma bullets", often with characteristic "donut" shape

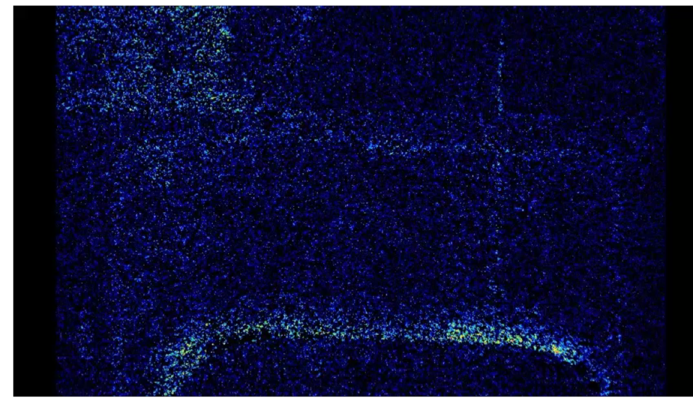
Planar He DBD plasma jet

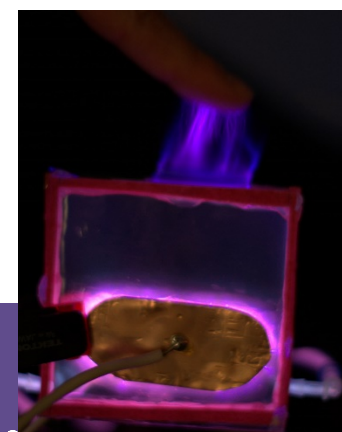


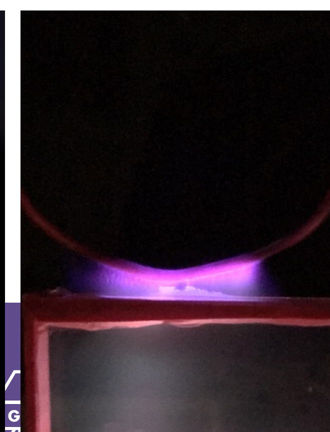


Planar He DBD plasma jet



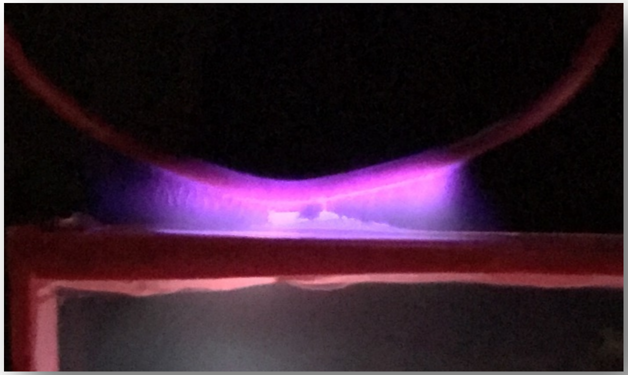






Need and Industrial Relevance

- Uniform plasma treatment with controllable parameters



Materials and Manufacturing

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

Plasma Medicine

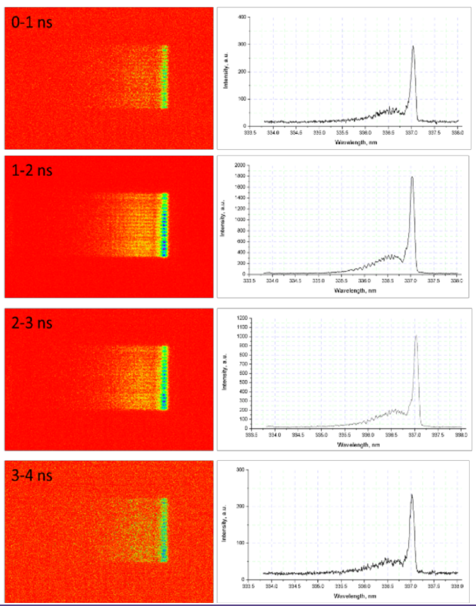
Project Goals

- **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)
- and to explore possibility of using Raman scattering for in situ detection/measurement of reactive chemistry

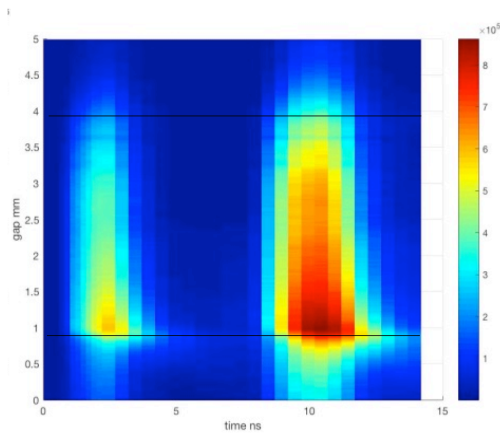
Objectives

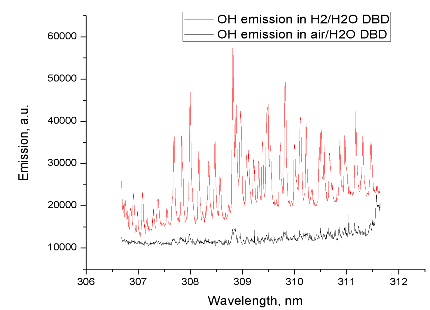
- **Quantitative characterization of planar He plasma jet uniformity and reactive chemistry**
  - imaging of the discharge dynamics and development and quantification of plasma uniformity
  - measurements of electric fields inside the plasma chamber, during propagation and at the treated surface
  - 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)
- Explore possibility of using Raman scattering for in situ detection/measurement of reactive chemistry

Approach/Methods

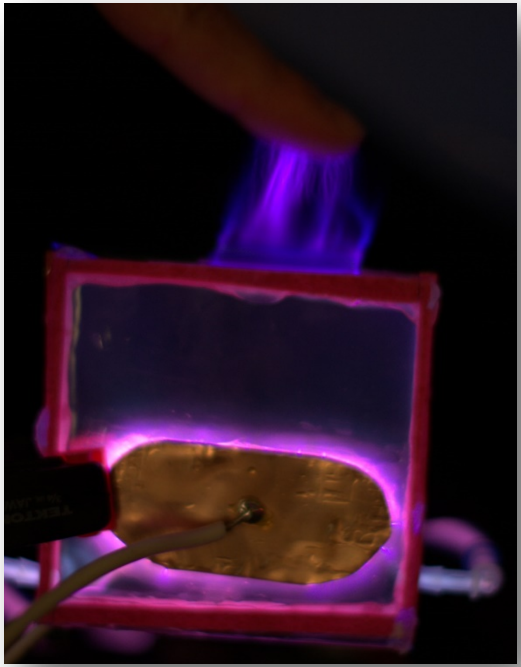


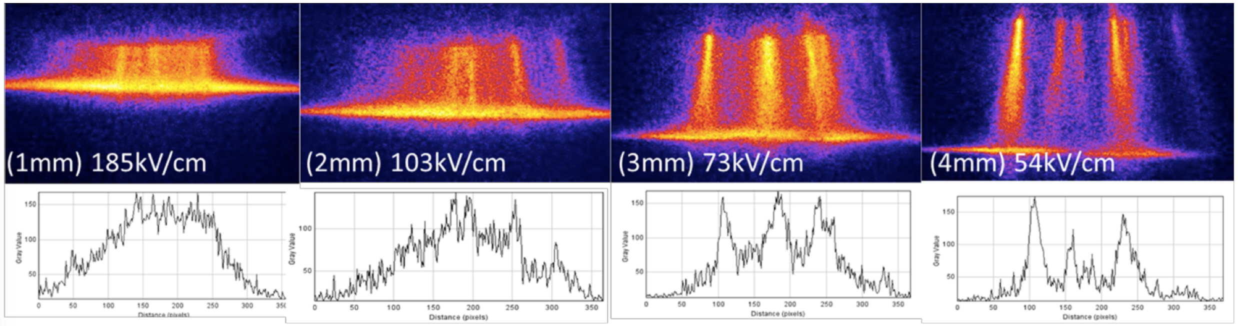
- **Fast imaging**
- **Optical emission spectroscopy**
- **Absorption spectroscopy**
- **Fluorescence spectroscopy**





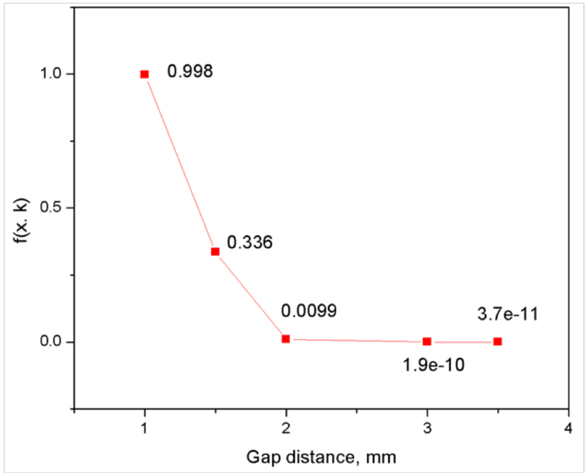
Task 1: quantification of uniformity



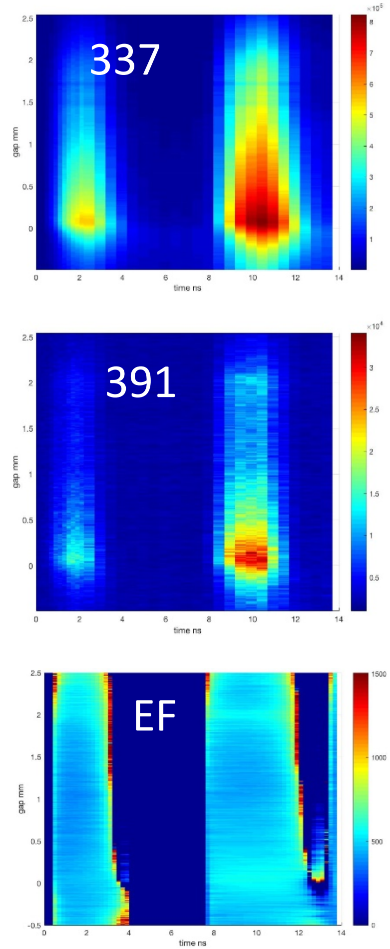


Chi-Square test: distribution of "brighter" pixels as measure of uniformity

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



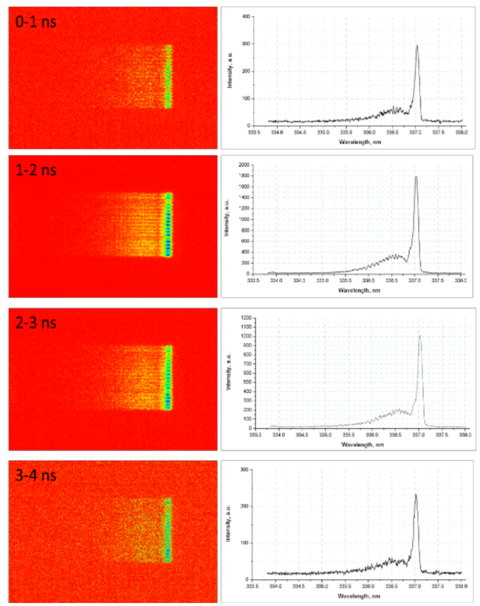
Task 2a: measurements of electric field

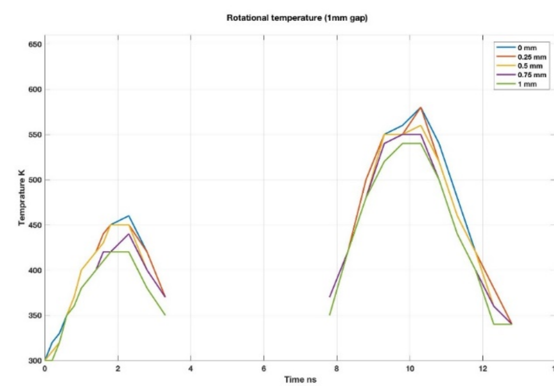


$$R_{391/337}\left(\frac{E}{N}\right) = 46\cdot A\cdot \exp\left[-89\left(\frac{E}{N}\right)^{-0.5}\right]$$
$$\cdot 0.065\exp\left[-402\left(\frac{E}{N}\right)^{-1.5}\right]$$

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

Task 2b: temperature measurements

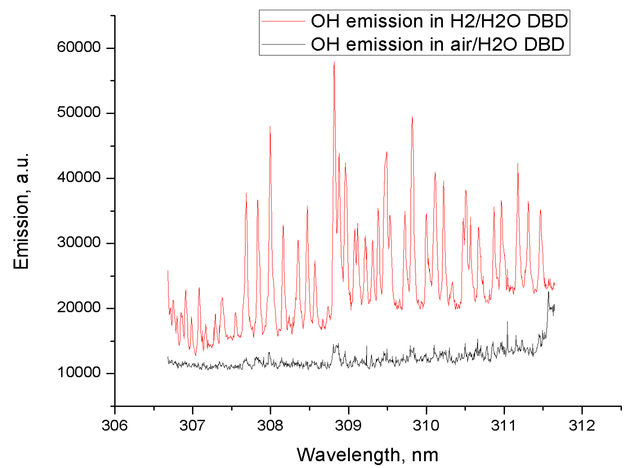




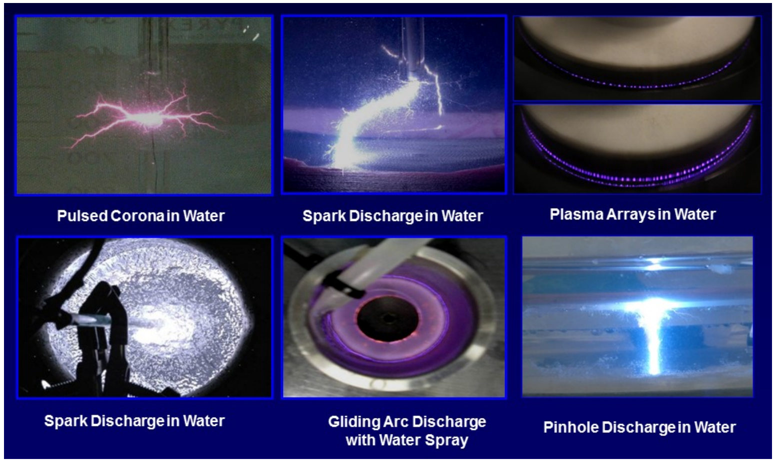
Task 3a: measurements of OH

- Absorption spectroscopy

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



Raman spectroscopy for in situ diagnostics of liquid chemistry?



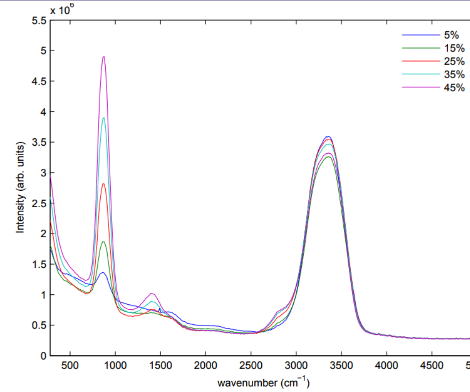


Figure 16. *Raman spectra of various H_2O_2/H_2O solutions in a cuvette. Measurements were made on eleven different concentrations of H_2O_2 ranging from 0% to 49.8 wt%, only five of which are plotted here for better clarity.*

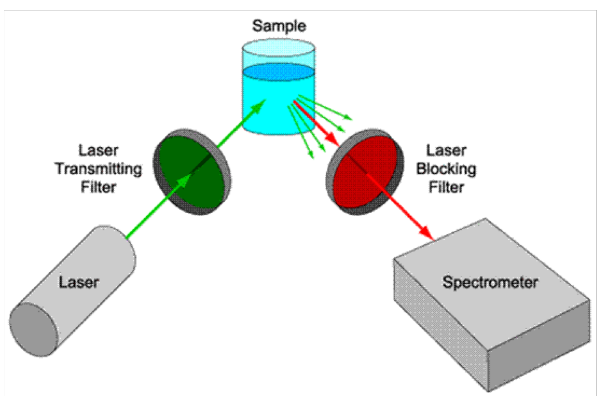


Table 1. Raman band assignments.

Raman shift (cm^{-1})	Assignment
878	OO stretch
1646	OH bend
1280	CO stretch
1388	CO stretch
2330	NN stretch
ca. 3400	OH stretch

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

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); development of *in situ* diagnostics
- **Goals:** to understand planar He plasma jet development and its characterization; development of *in situ* diagnostics
- **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; development of *in situ* diagnostics
- **Project Duration, Budget: 3** years, $120k