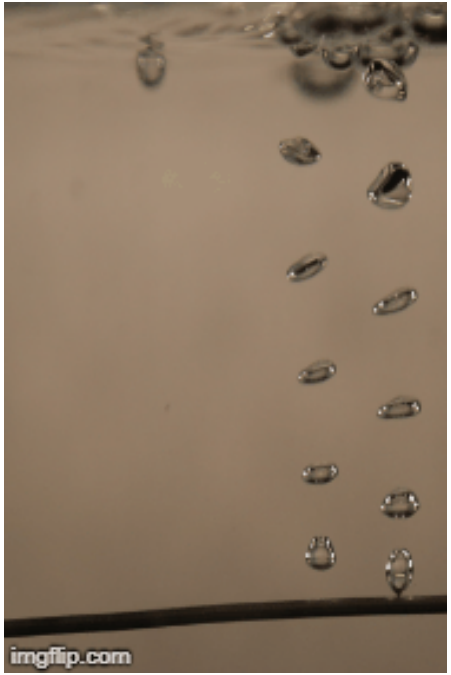
Plasmas for Life Science Applications at NC State University

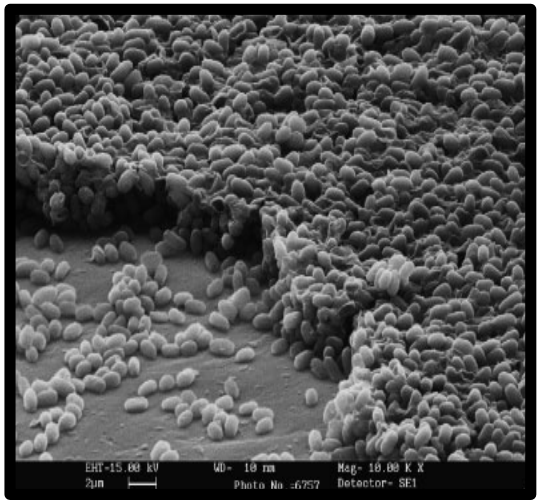
Presented by:
William Murray

Graduate Advisor:
Dr. Katharina Stapelmann

Presented for:
PPPL Grad. Summer School
Princeton, NJ
08/12/2019



Interest in plasmas for biological, medical, and agricultural applications has grown in the 15 years

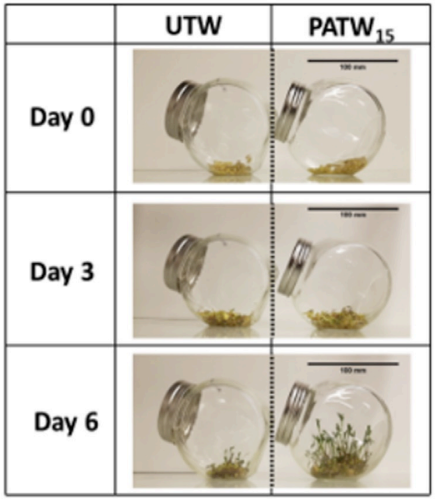


Biological: Bacteria Sterilization

Kylián, O., T. Sasaki, and F. Rossi. "Plasma sterilization of Geobacillus stearothermophilus by O 2: N 2 RF inductively coupled plasma." *The European Physical Journal-Applied Physics* 34.2 (2006): 139-142.

Medicine: Wound Healing

Fridman, Alexander A., and Gary G. Friedman. *Plasma medicine*. Chichester, UK:: John Wiley & Sons, 2013.



Agriculture: Nitrate Injection

Judée, Florian, et al. "Plasma-activation of tap water using DBD for agronomy applications: Identification and quantification of long lifetime chemical species and production/consumption mechanisms." *Water research* 133 (2018): 47-59.

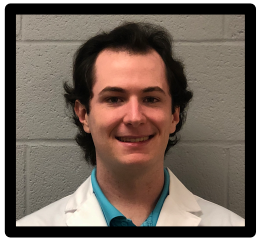
The Plasma for Life Sciences Lab at NC State formed in 2017 to join this growing and diverse field

Dr. Katharina Stapelmann
PLS Lab Director

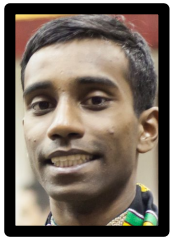
Duncan Trosan
PhD Student
Medical DBD Characterization

Brayden Meyers
PhD Student
COST Jet Characterization

Dr. Pietro Raneiri
Post-Doc Researcher



William Murray
PhD Student
Plasma-Water Treatment



Naveen Pillai
PhD Student
CFD & EM Coupled Simulations

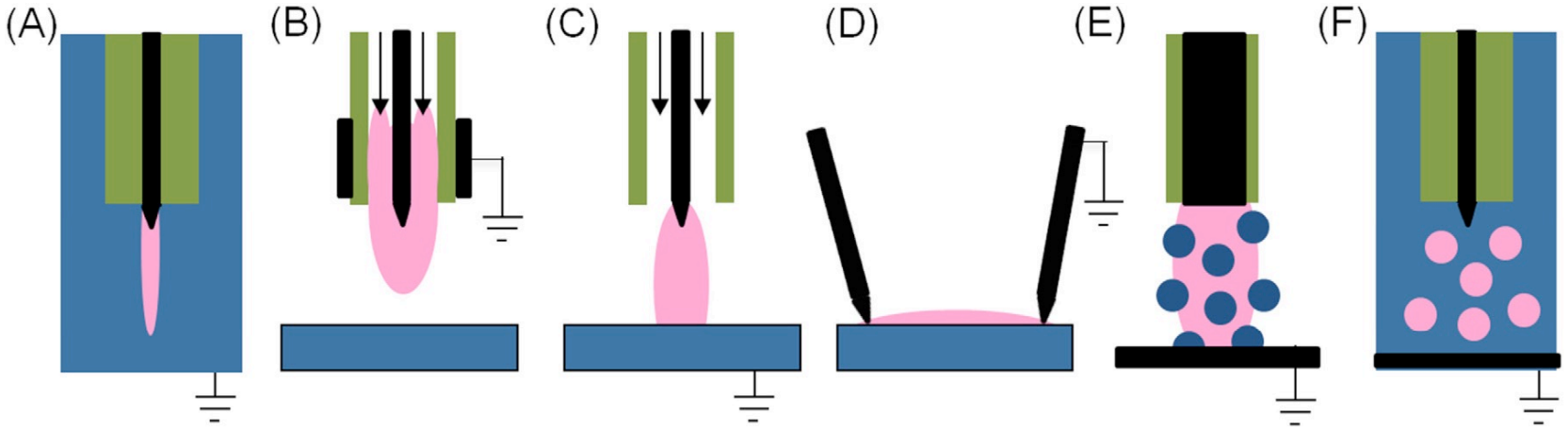
Plasma can decompose organic compounds in liquids that are difficult to remediate with chemical methods

Chemical Decomposition

- Methylene-blue is a dye that is hard to decompose chemically
- Plasma treatment decomposes M-B, clearing the solution
- Other organics may be decomposed with plasmas by changing plasma settings

Magureanu, Monica, et al. "Decomposition of methylene blue in water by corona discharges." *Plasma Chemistry and Plasma Processing* 28.6 (2008): 677-688.

Plasma treatment of water is limited by the breakdown voltage of water and contact area with gas

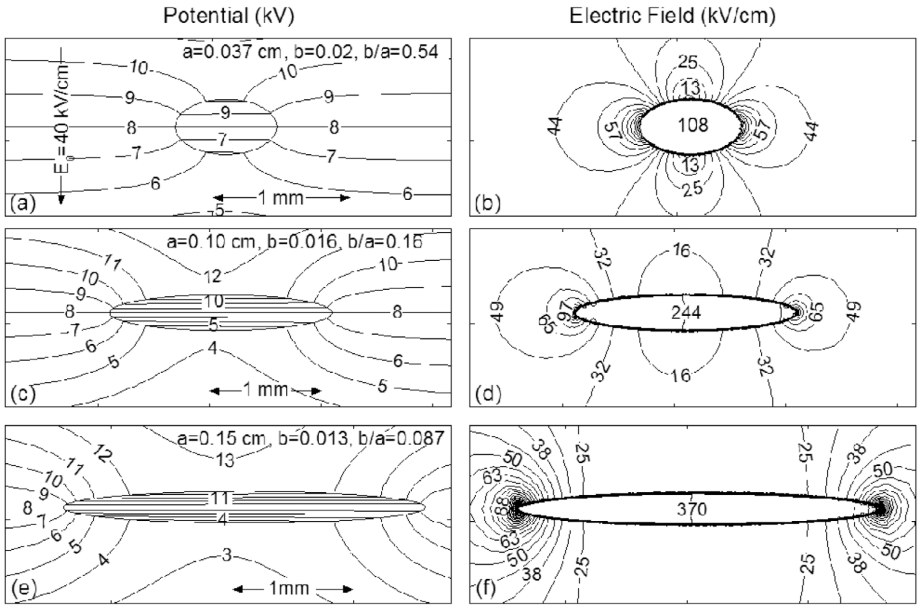


Air: $V_{breakdown} \approx 3\ MV/m$

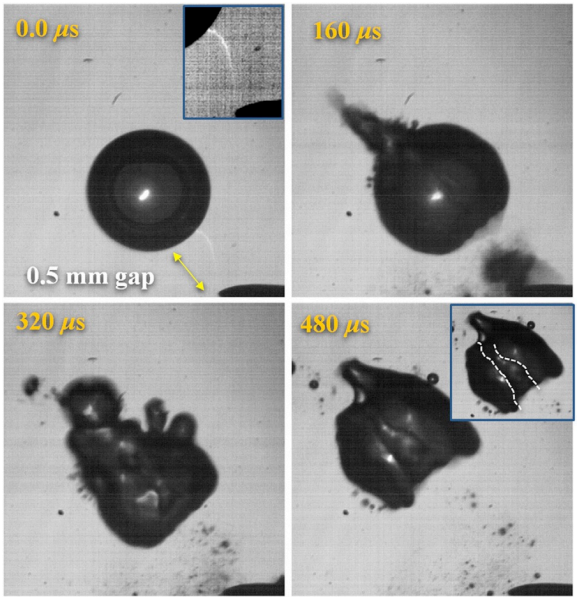
Water: $V_{breakdown} \approx 65\ MV/m$

P J Bruggeman et al 2016 Plasma Sources Sci. Technol.25 053002

The shape and size of the bubble is strongly correlated to its ability to form a plasma via the E-field profile

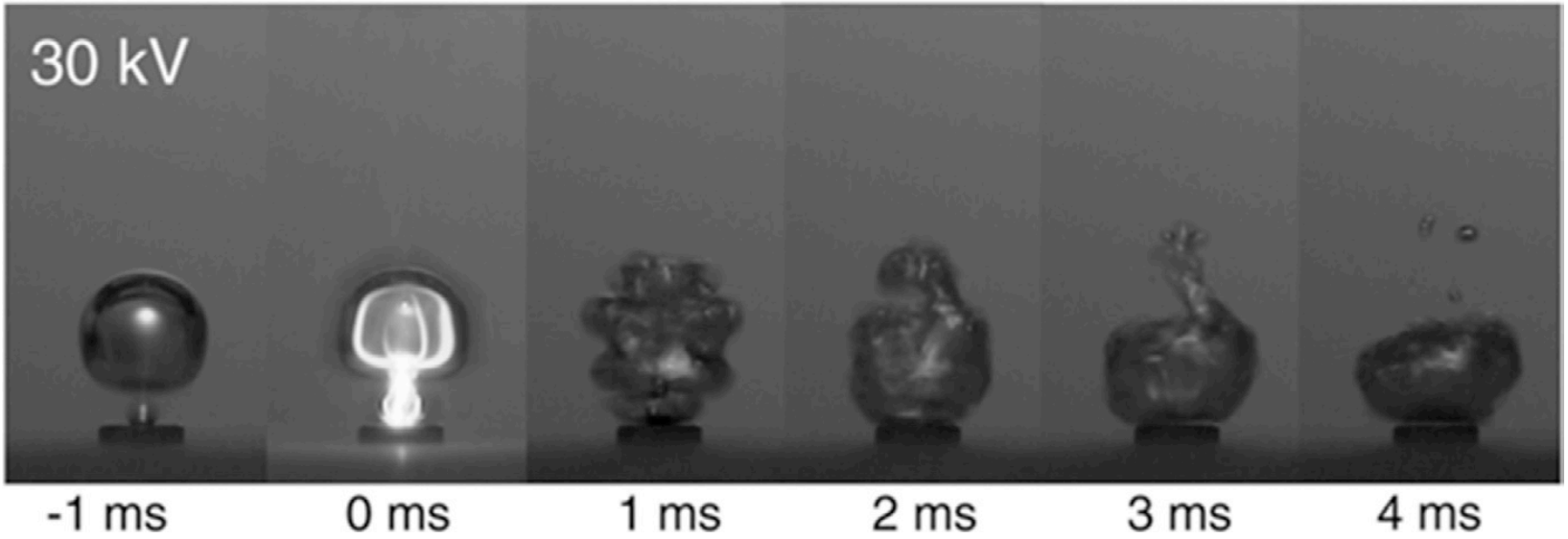


Babaeva, Natalia Yu, et al. "Streamer breakdown in elongated, compressed and tilted bubbles immersed in water." *Journal of Physics D: Applied Physics* 50.36 (2017): 364001.



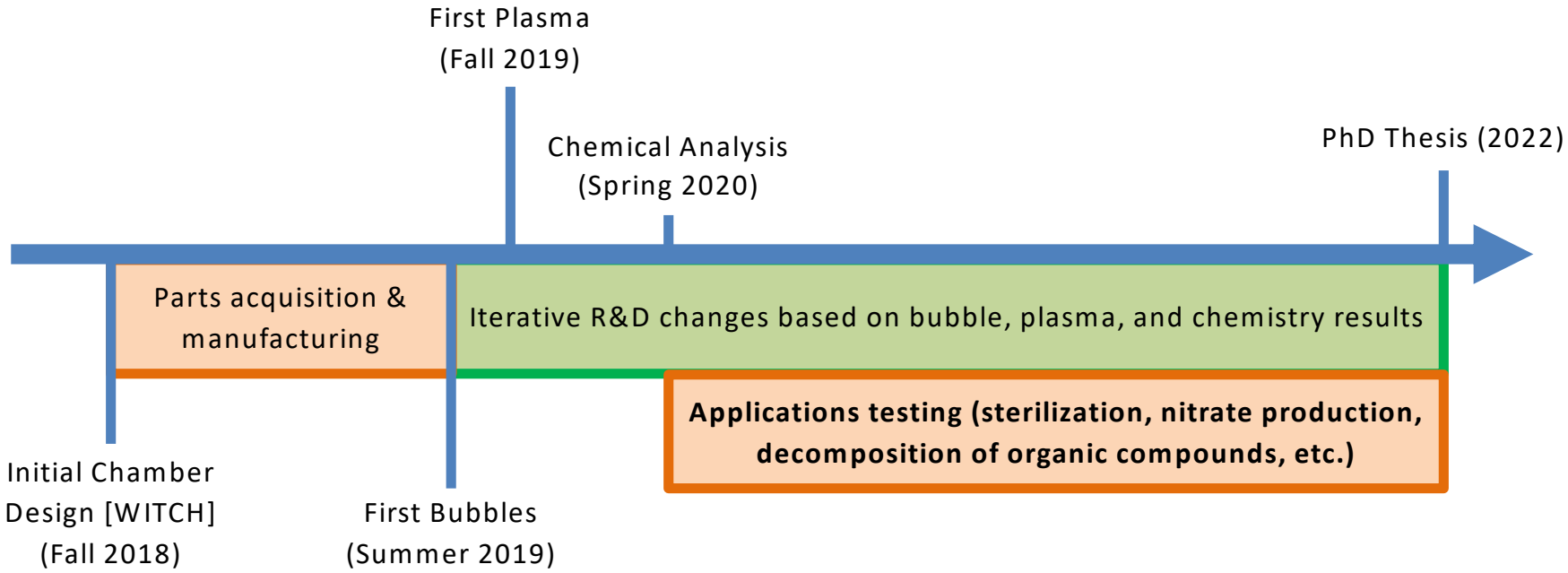
B S Sommers and J E Foster 2014 *Plasma Sources Sci. Technol.* **23** 015020

Plasma-bubble ignition is coupled with the shape of the bubble, which deforms upon ignition

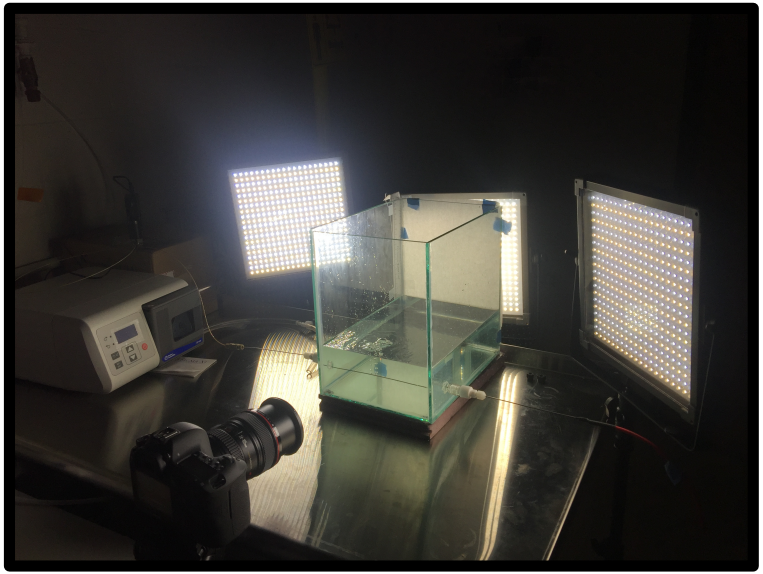


P J Bruggeman et al 2016 Plasma Sources Sci. Technol.25 053002

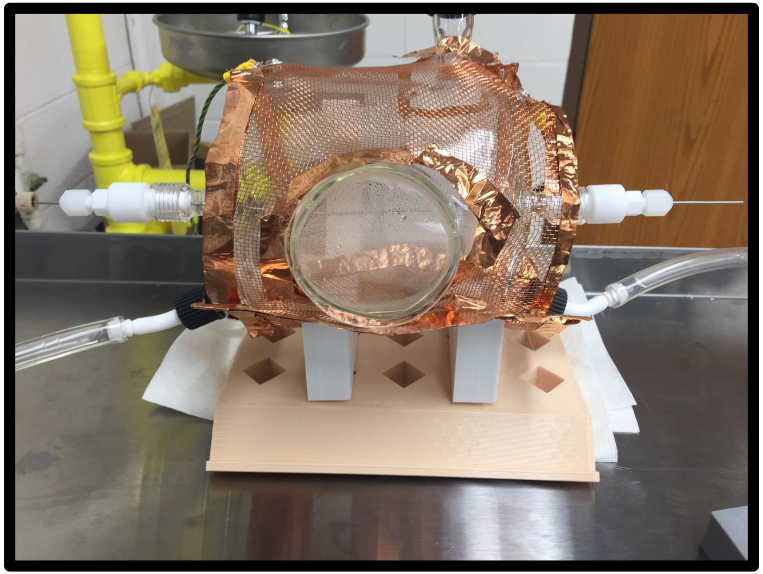
The purpose of this research is to characterize large-scale plasma-bubble chambers for water treatment



Two bubble chambers have been created to study plasma behavior in bubbles

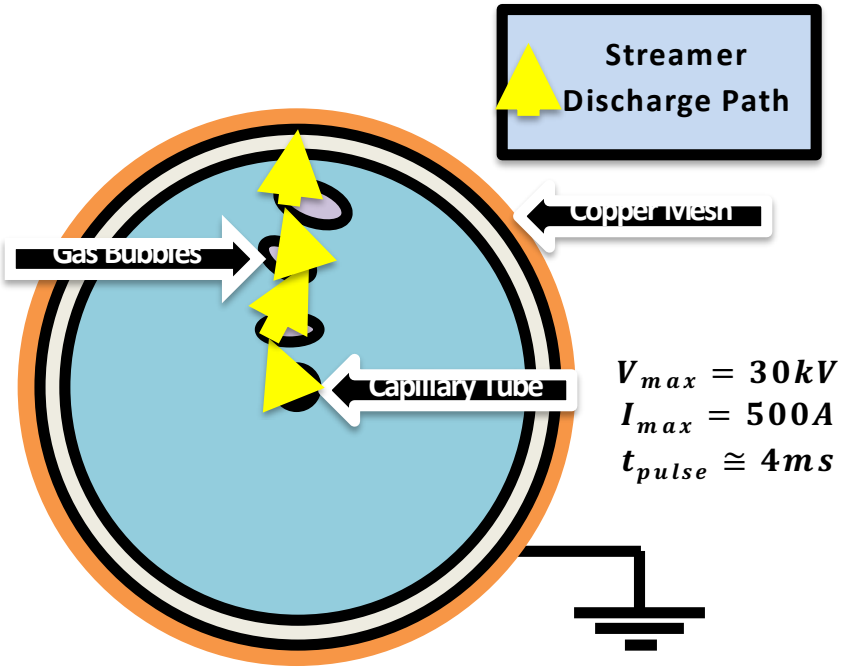


CAULDRON – Bubble Characterization Chamber

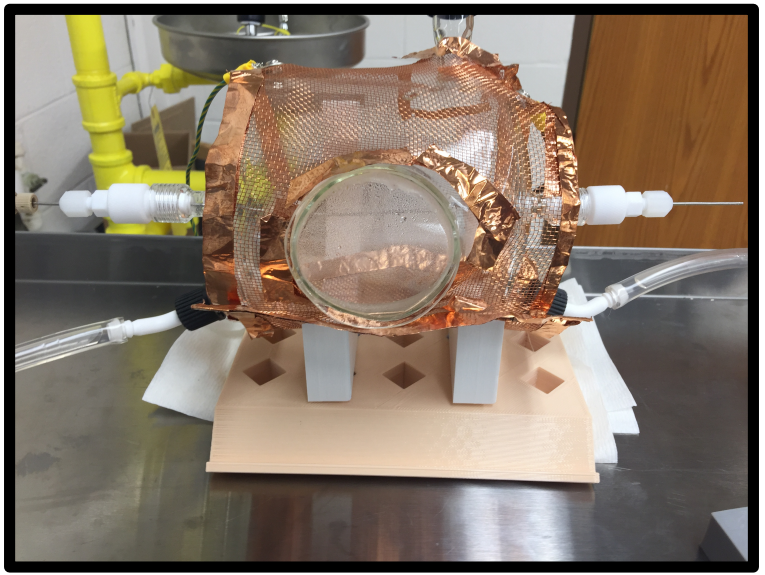


WITCH – Plasma Treatment Chamber

The WITCH ignites plasma with a high voltage potential arranged in a barrel-capacitor configuration



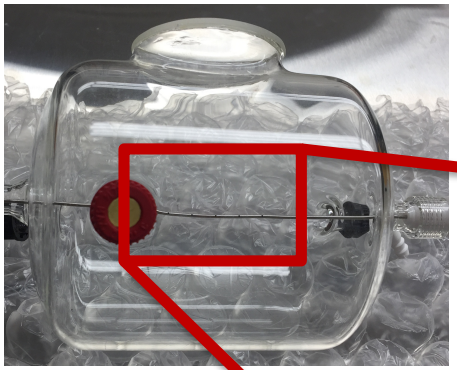
$$V_{max} = 30kV$$
$$I_{max} = 500A$$
$$t_{pulse} \cong 4ms$$



WITCH:

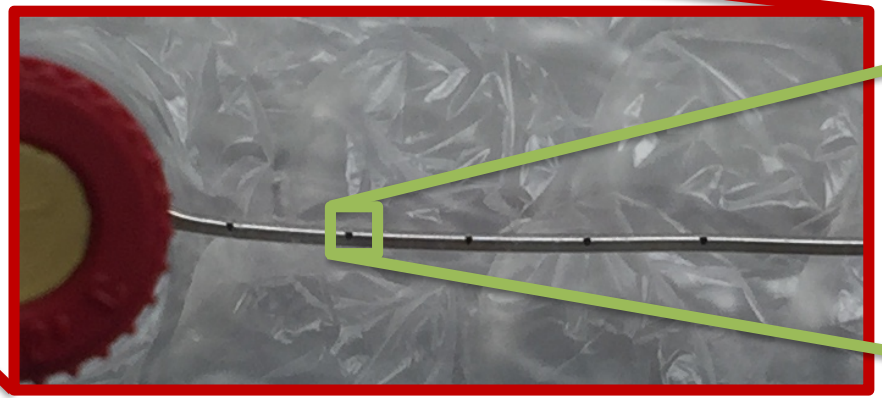
"**W**ater **I**onization **T**wo-phase **Ch**amber"

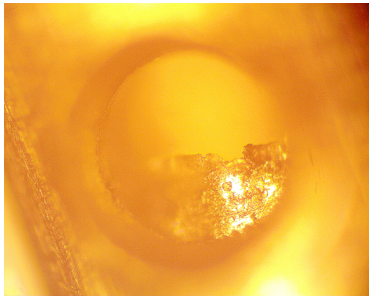
The capillary tubes are small to mimic the behavior of a wire, and are perforated with small holes for the gas

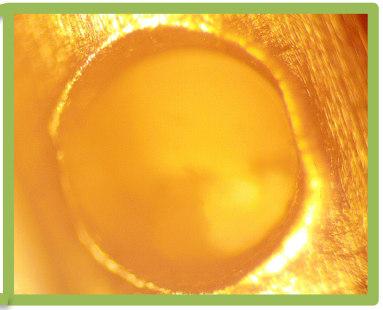


D_{hole} limited by mechanical drilling,
Laser drilling prohibitively expensive

$D_{hole} \cong 0.5mm$

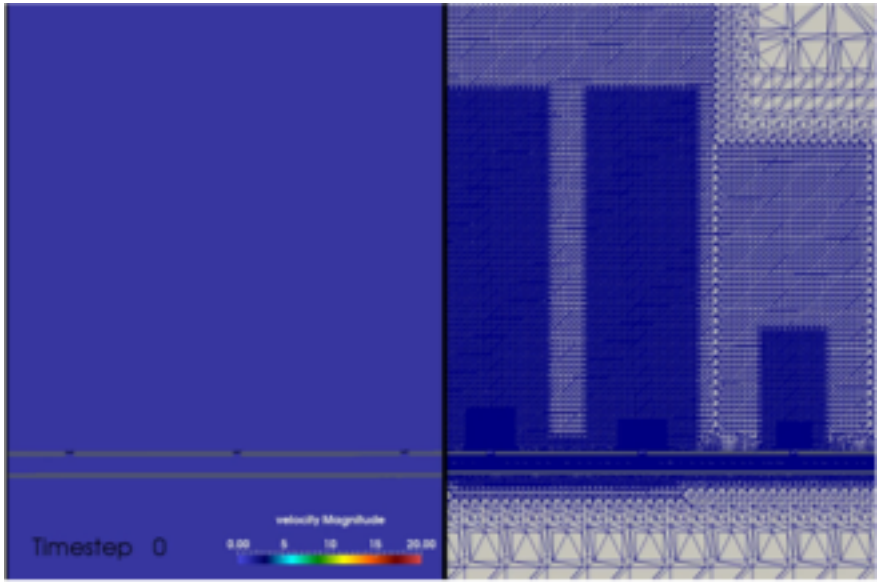




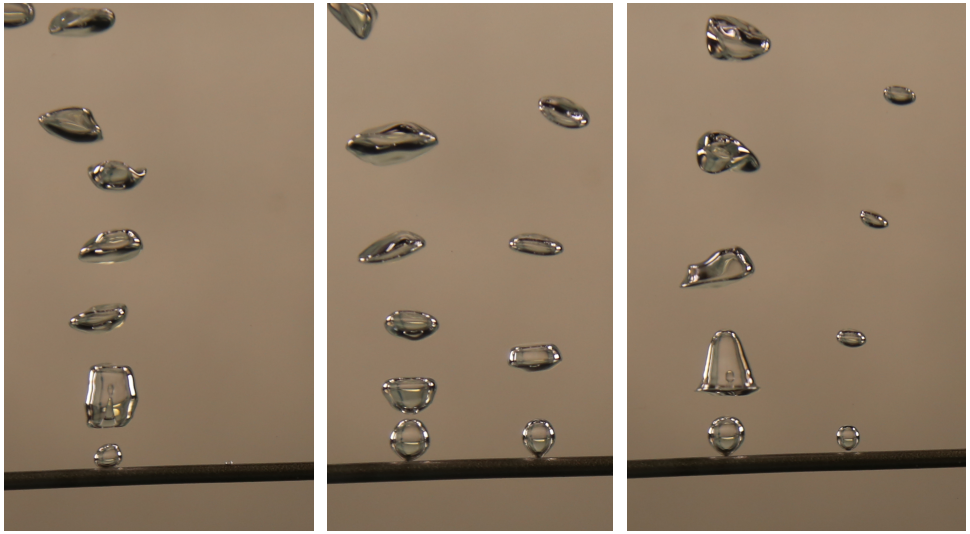


CFD simulations are also in place to assist in design of tube to obtain desirable bubbles for plasma ignition

Courtesy: Naveen Pillai



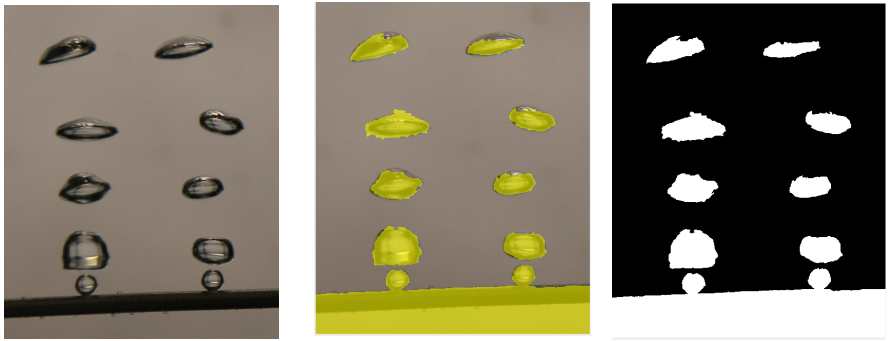
CFD Simulation of Tube (sequential snapshots)



CAULDRON Photographs (arbitrary snapshots)

Image processing is done in MATLAB to identify and count bubbles seen in each photograph

Murray (2019)



Comments on Bubble Photography

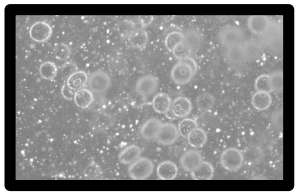
- Capillary tube serves as ruler ($D_o = 1.6mm$)
- Light deflections result in errors in edge detection
- Higher contrast photos are easier to detect

Ratering (2018)

Ratering, Caroling. "Konstruktion Und Charakterisierung Eines Plasma-Wasser-Aufbaus." *Ruhr-Universität Bochum*, 2018.

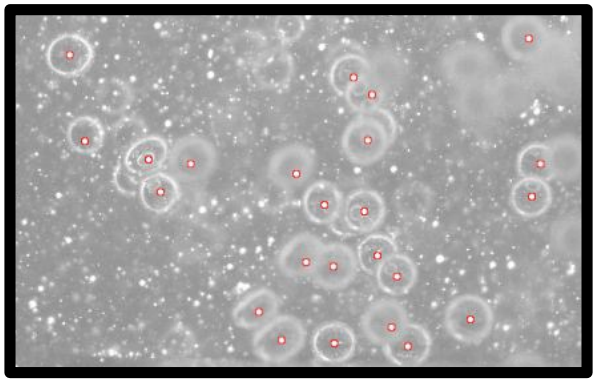
Machine learning looks promising to supplement traditional image processing for bubble analysis

Original image



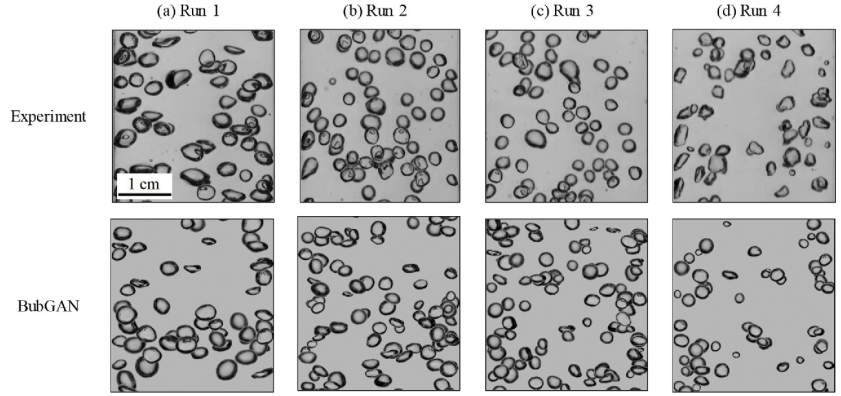
CNN Processing

ML bubble identification



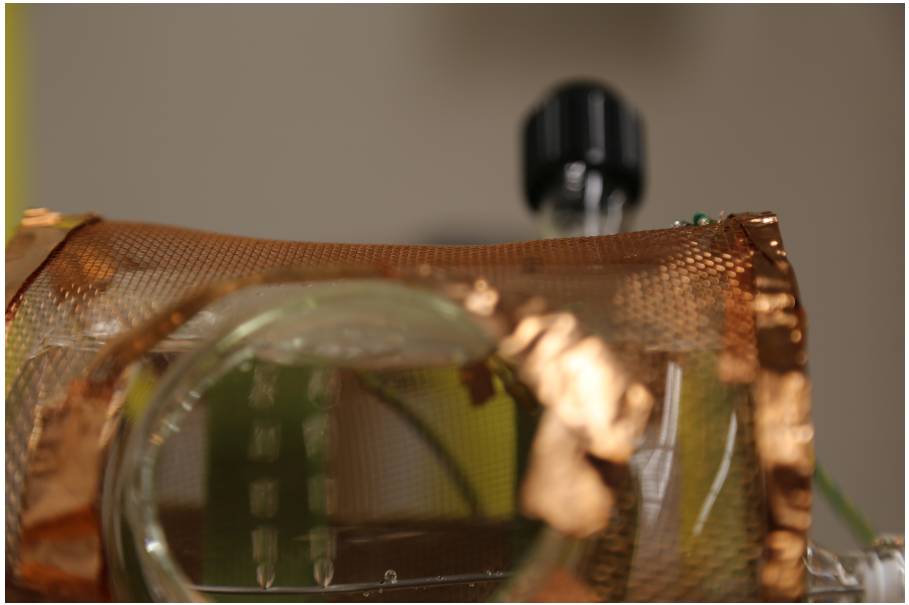
Poletaev, I. E., K. S. Pervunin, and M. P. Tokarev. "Artificial neural network for bubbles pattern recognition on the images." *Journal of Physics: Conference Series*. Vol. 754. No. 7. IOP Publishing, 2016.

Producing artificial bubbles with AI
to create testing data for ML bubble recognition



Fu, Yucheng, and Yang Liu. "BubGAN: Bubble generative adversarial networks for synthesizing realistic bubbly flow images." *Chemical Engineering Science* 204 (2019): 35-47.

The WITCH & the CAULDRON will combine plasmas with fluid mechanics to improve the throughput of liquid-plasma systems



Contact Information

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Now open for questions, comments, and suggestions