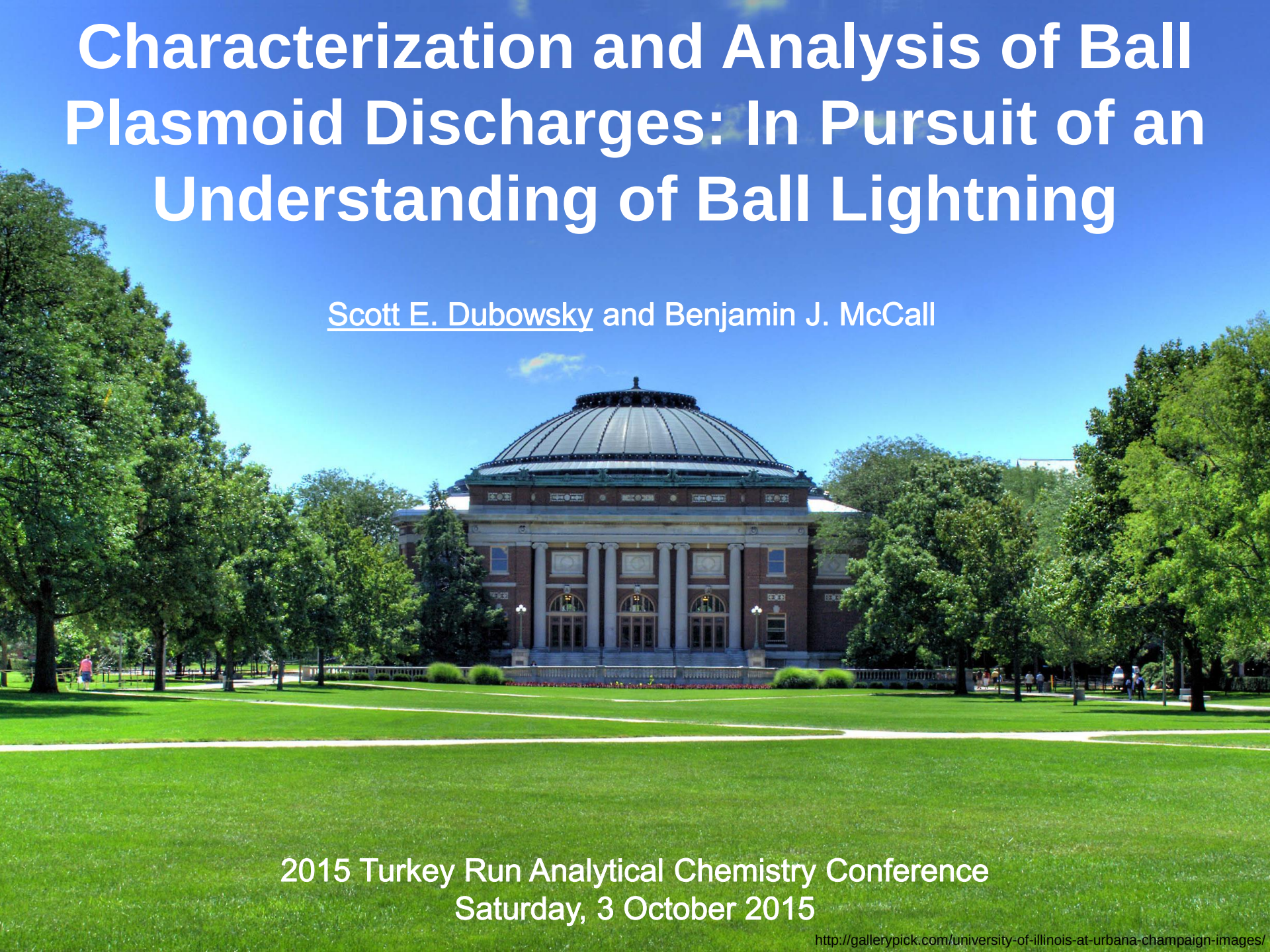
Characterization and Analysis of Ball Plasmoid Discharges: In Pursuit of an Understanding of Ball Lightning

Scott E. Dubowsky and Benjamin J. McCall

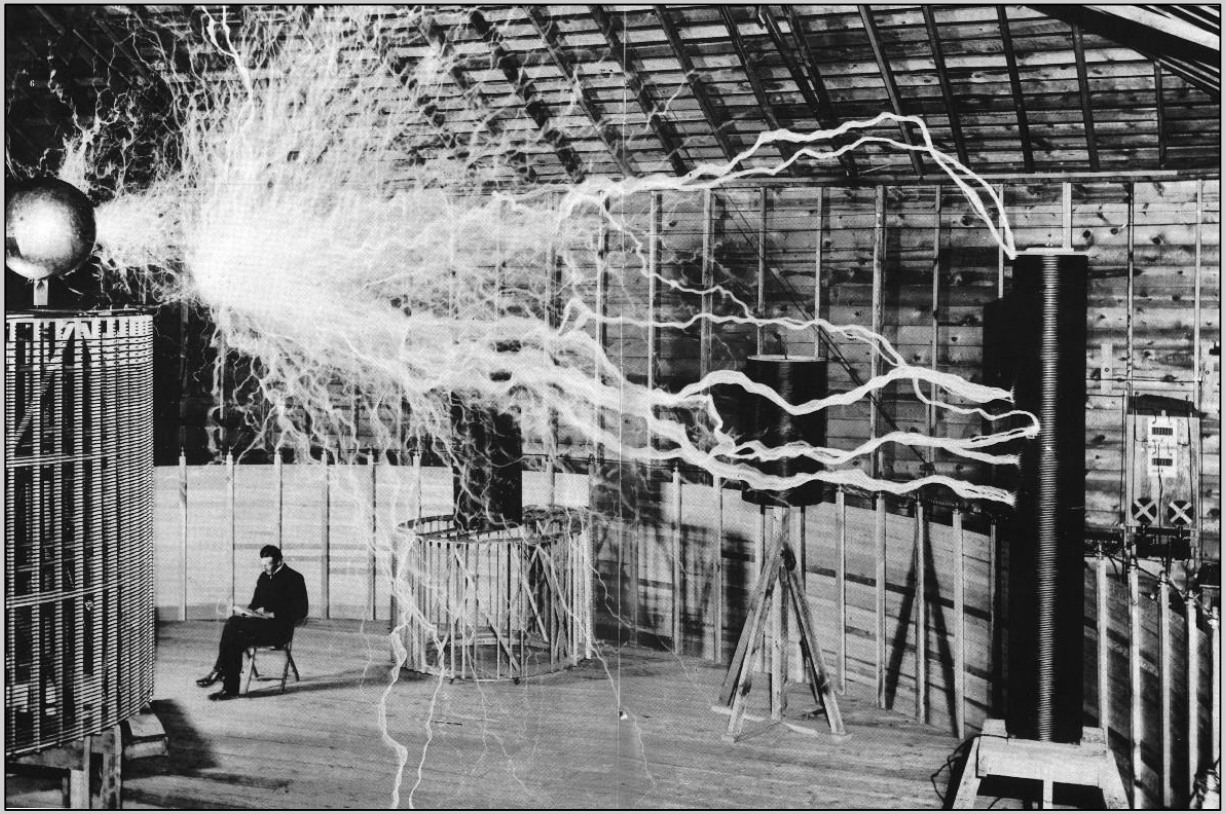


2015 Turkey Run Analytical Chemistry Conference
Saturday, 3 October 2015

http://gallerypick.com/university-of-illinois-at-urbana-champaign-images/

Outline

- Introduction and Motivation
  - Ball Lightning
- Discharge Characterization
- Mass Spectrometry
- IR Emission Spectroscopy
- Conclusions
- Future Work



http://drevol.com/en/blog/Nikola-Tesla-158-years-birthday-009

Ball Lightning

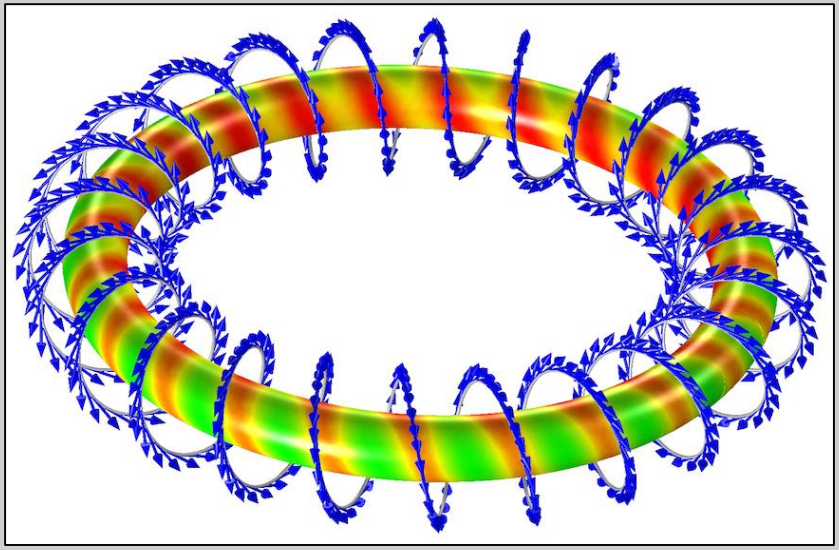
- Sphere of lightning
  - Up to 1m diameter
  - Lasts tens of seconds
- Difficult to observe in the field
  - 1 ball for every 10^6 lightning strikes
- Lifetime unexplained
  - Water dissociation?
  - E and B fields?
  - Electromagnetic cavity?

Image courtesy of the Wikimedia Commons

Ter Haar, D. *Phys. Scr*. **1989**, 39, 735
Versteegh et al. *Plasma Sources Sci. Technol.* **2008,** *17,* 024014
Endean, V.G. *Nat.* ***1976****, 273,* 753-755

Plasmoids

- Self-contained plasma
- Definite shape
  - Toroidal
  - Spheroidal
- High-voltage capacitive discharge over weak electrolyte



http://www.comsol.com/blogs/exploiting-symmetry-simplify-magnetic-field-modeling/

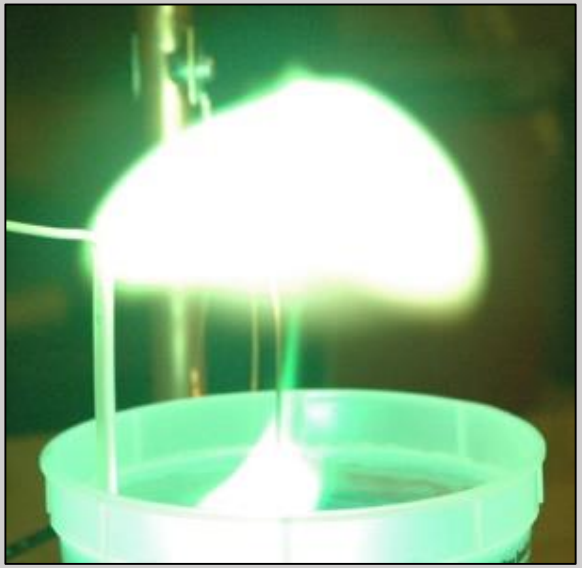
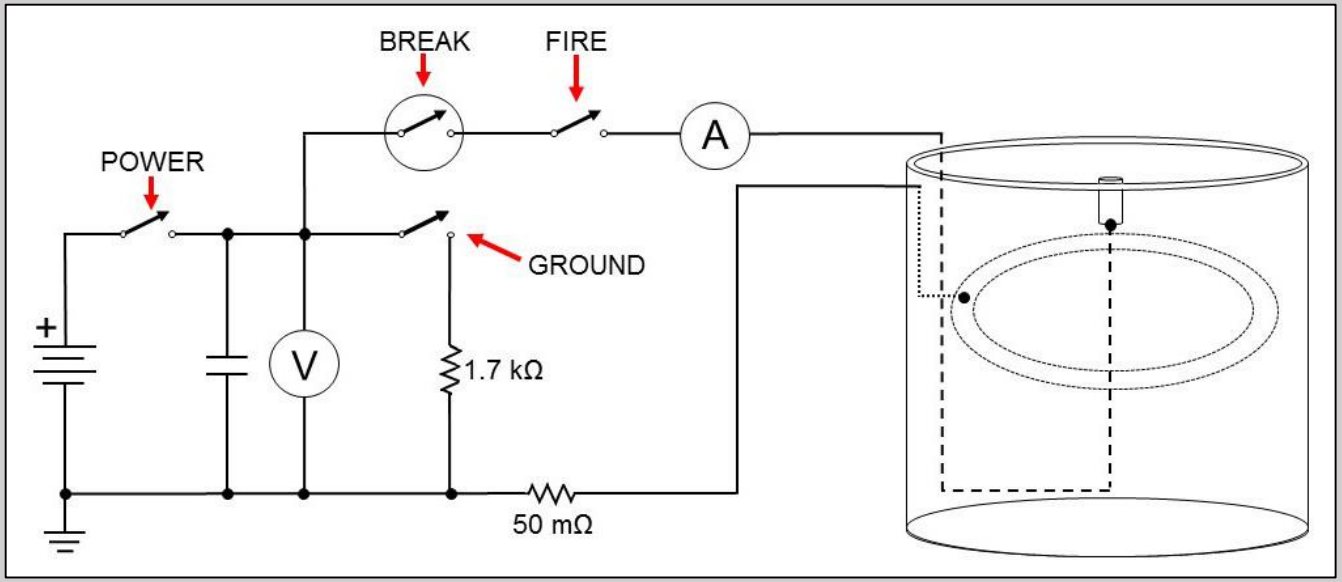


Image courtesy of the Wikimedia Commons

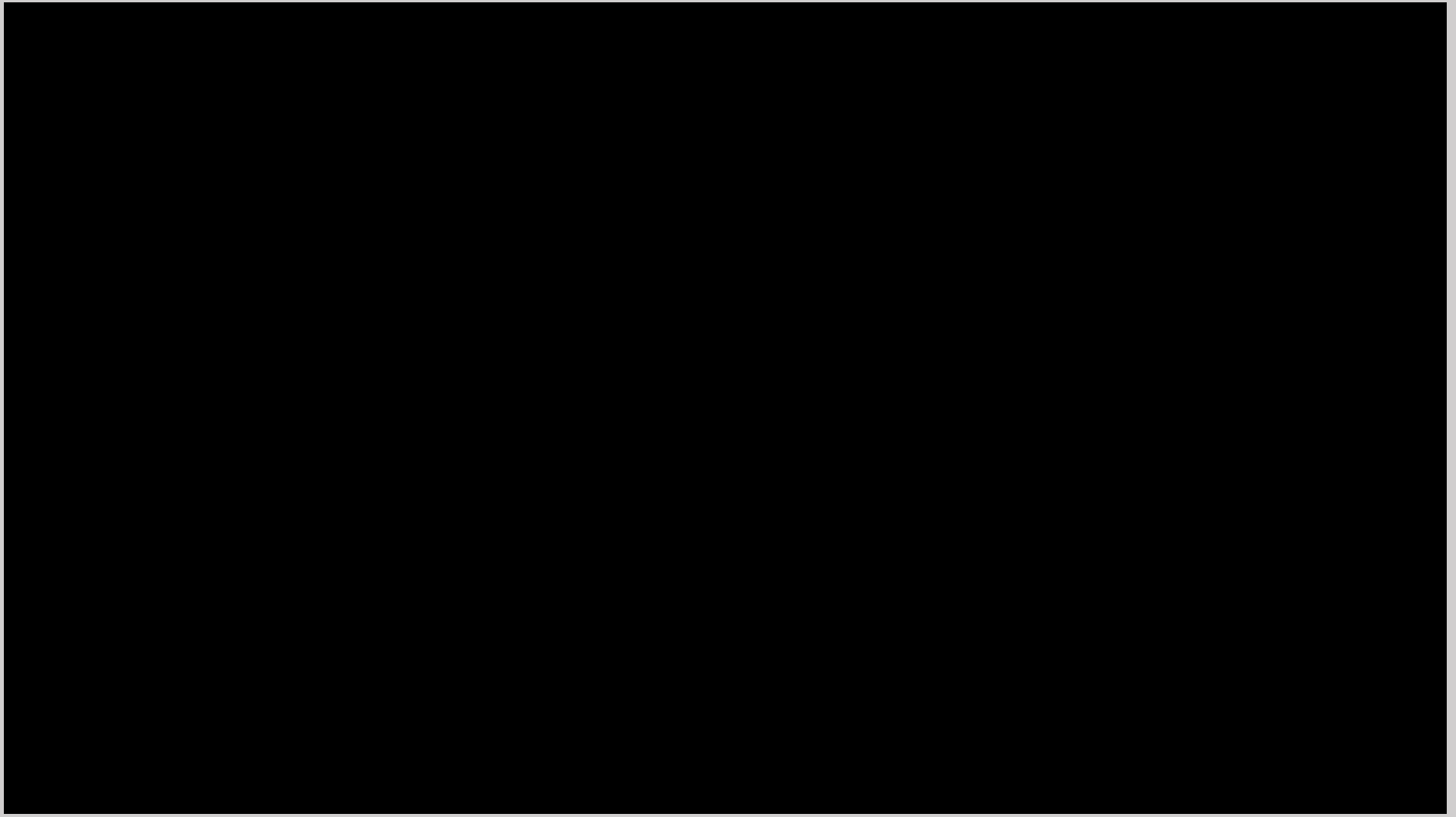
Bostick W.H. *Phys. Rev.* **1956**, *104* (2), 292
Egorov et al. *Phys. –Uspekhi.* **2004**, *47*, 99-101
Friday et al. *J. Phys. Chem. A,* **2013**, *117,* 9931

Hardware



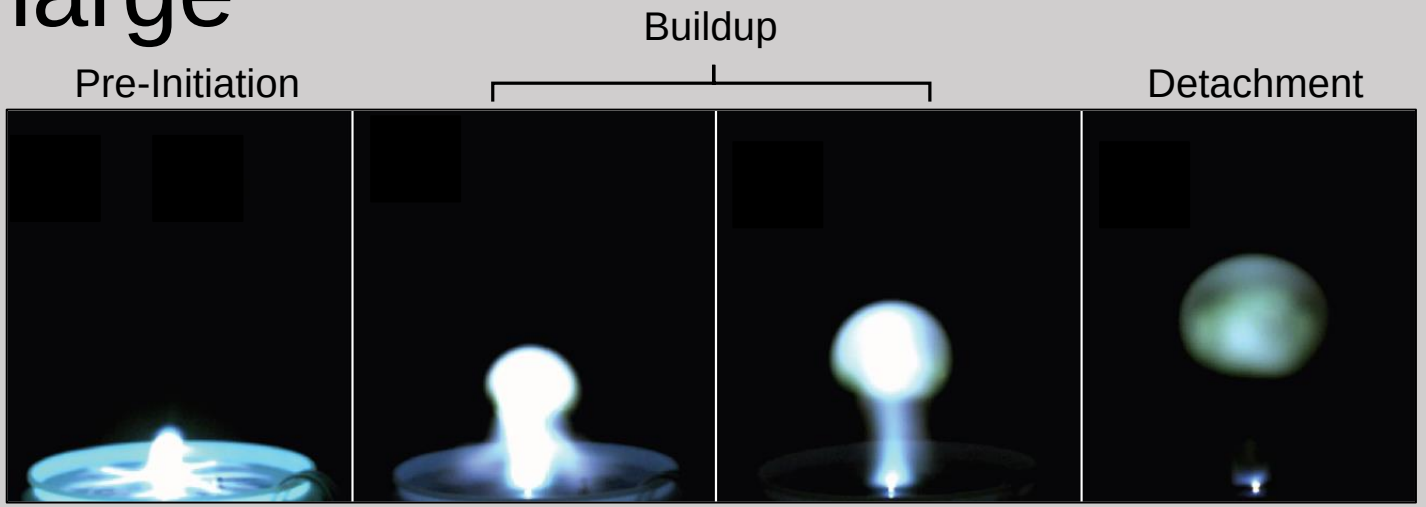
Dubowsky et al. *Int. J. Mass Spectrom.* **2015**, *376*, 39-45

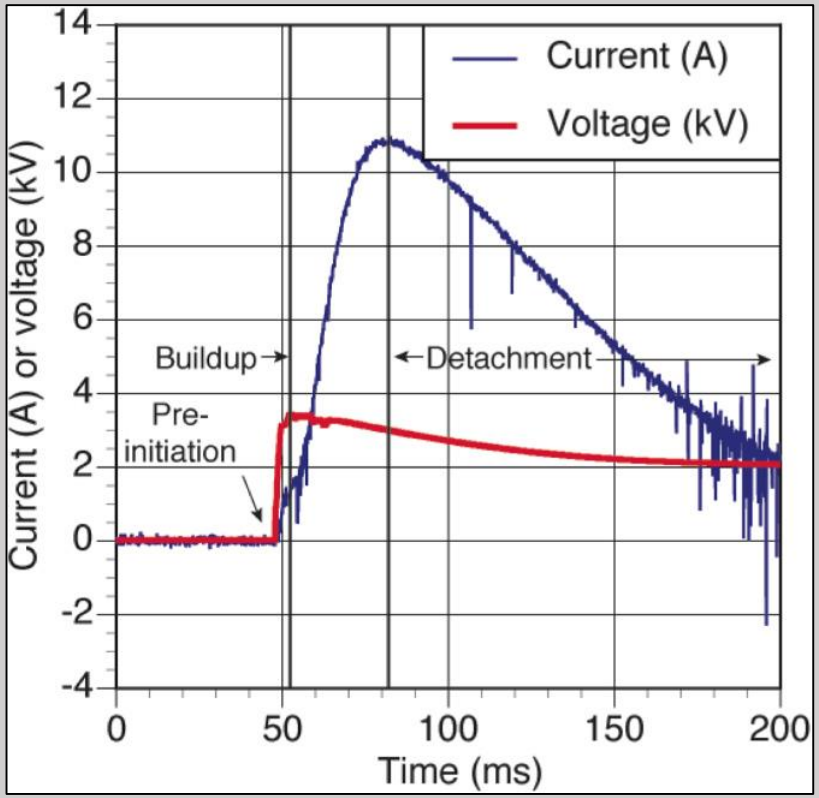
Discharge

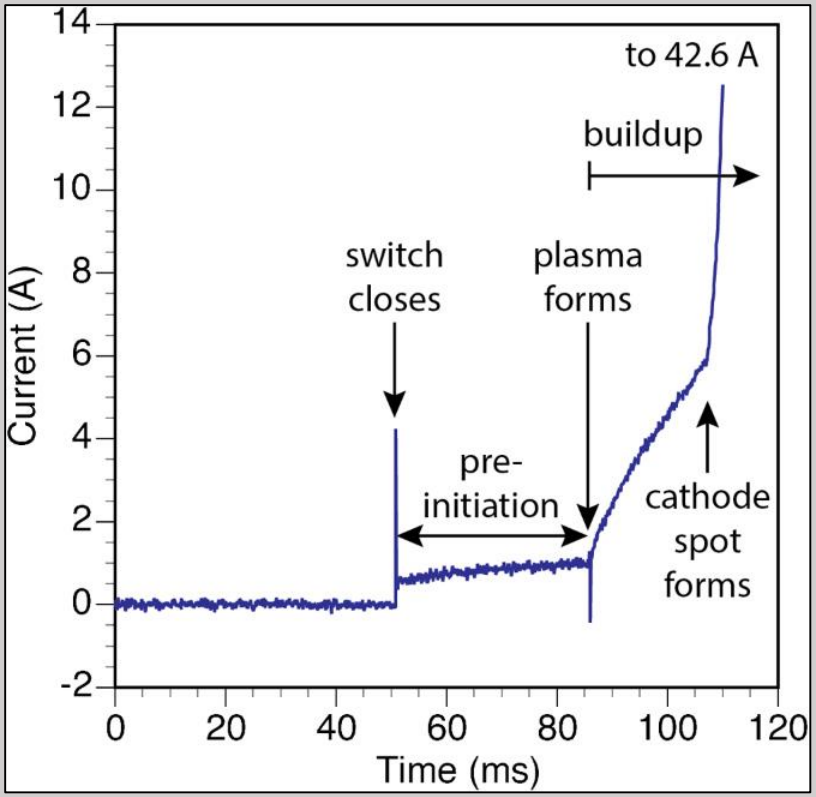


Video Length: 400 milliseconds
Plasmoid Diameter: 20 centimeters

Discharge







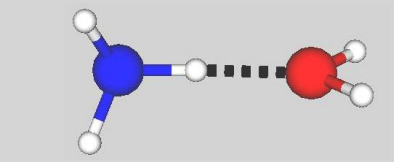
Dubowsky et al. *Int. J. Mass Spectrom.* **2015**, *376*, 39-45
Stephan et al. *Plasma Sour. Sci. Technol.* **2013**, *22*, 025018

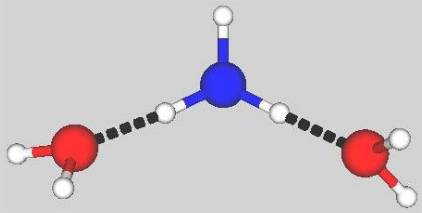
Previous Work

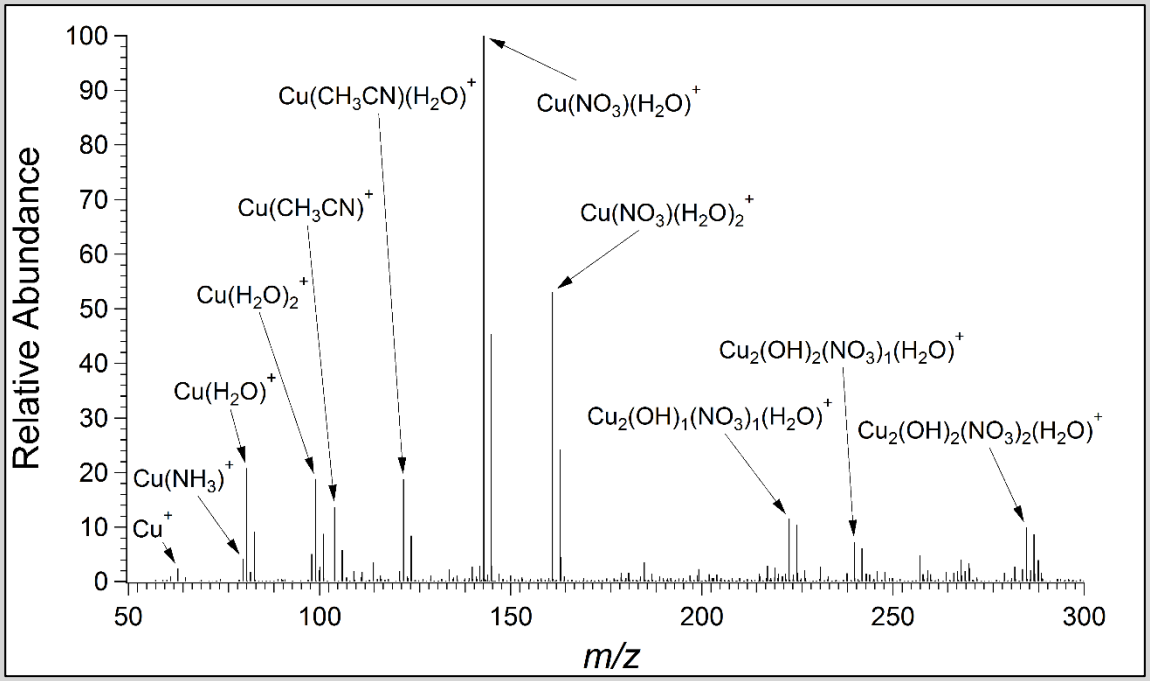
- Infrared absorption spectroscopy
  - Presence of water and CO_2
- Schlieren Imaging
  - Cooler “envelope” separating hot gas from ambient air
  - Plasmoid is homogenous; density 66% that of air
- UV-vis emission spectroscopy
  - Emission from several atoms and some molecules
    - Ca, Cu, Na, Al, K, Sr, Fe, H
    - Ca^+, Sr^+, Mg^+
    - OH, CaOH
    - T_{OH} estimated to be 15,000 K at 115 ms
  - Estimation of electron density and temperature
    - $n_e = 10^{16}$ cm^{-3} at 10 ms, 10^{14} cm^{-3} at 75 ms (Stark broadening)
    - T_e = 2000-5000 K across lifetime (intensity ratios)

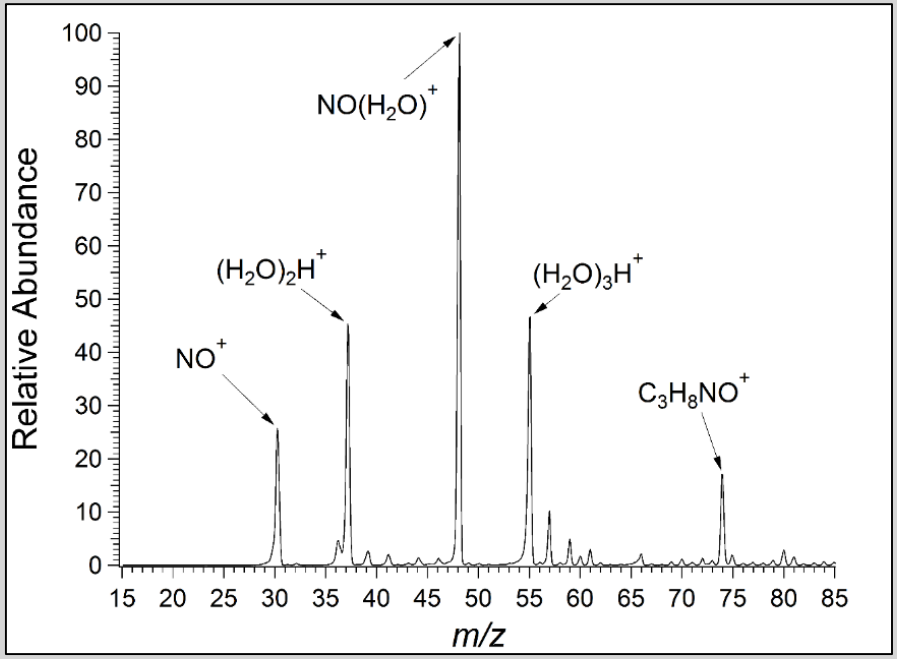
Friday et al. *J. Phys. Chem. A,* **2013**, *117,* 9931
Versteegh et al. *Plasma Sources Sci. Technol.* **2008,** *17,* 024014

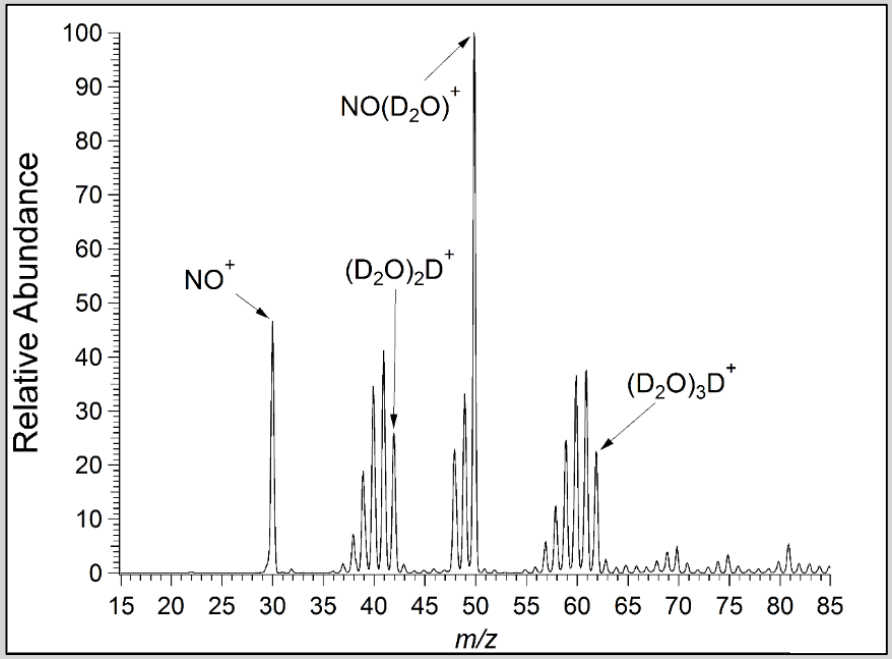
Previous Work











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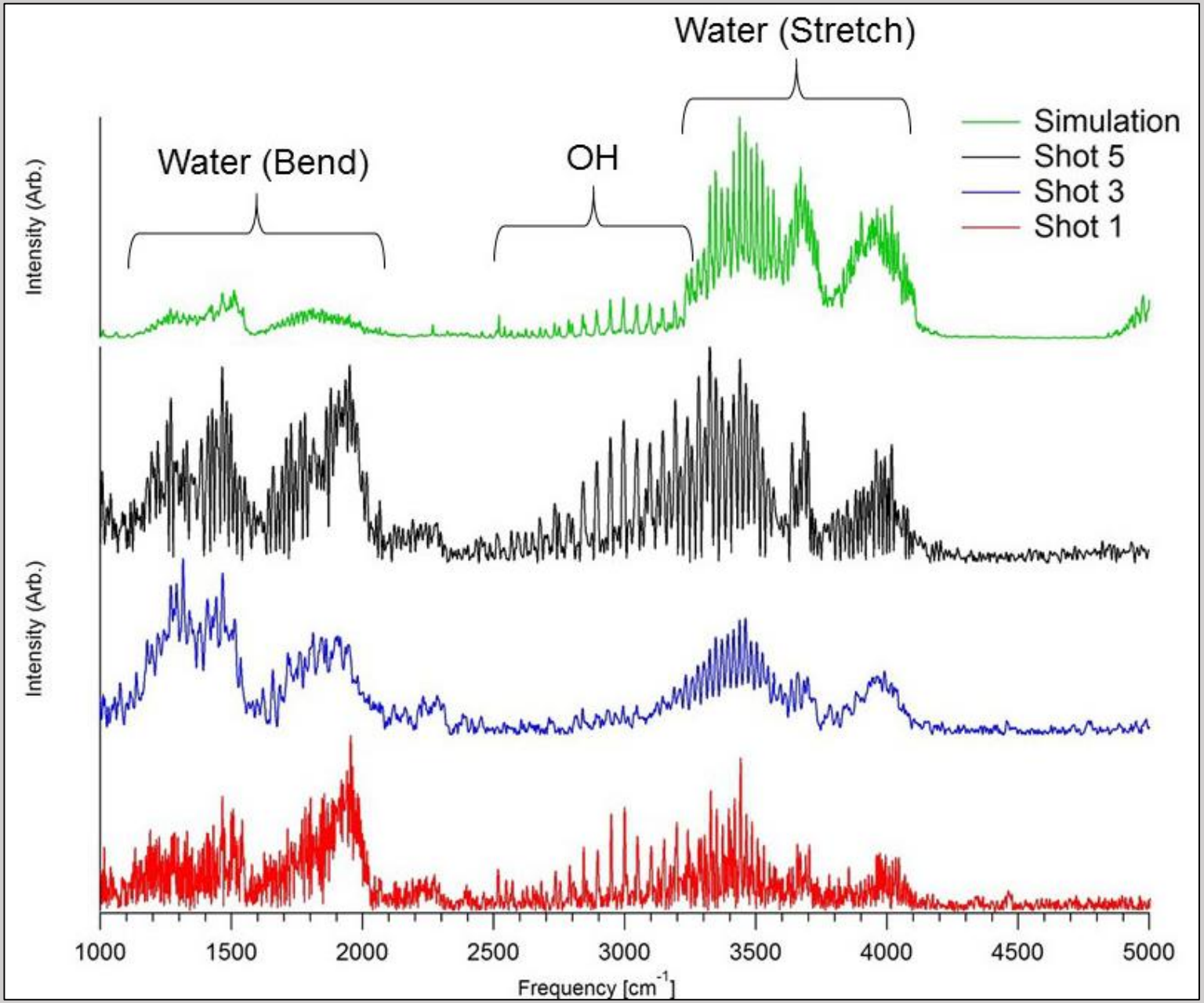
Emission Spectroscopy

- Bruker Vertex 70 FTIR spectrometer
  - 4 cm^{-1} resolution
- External optics
  - Parabolic mirrors
  - 1.6 m pathlength
  - Aligned using HeNe (spectrometer)
- “Screen” placed in front of plasmoid
  - Remove cathode glow / reflections

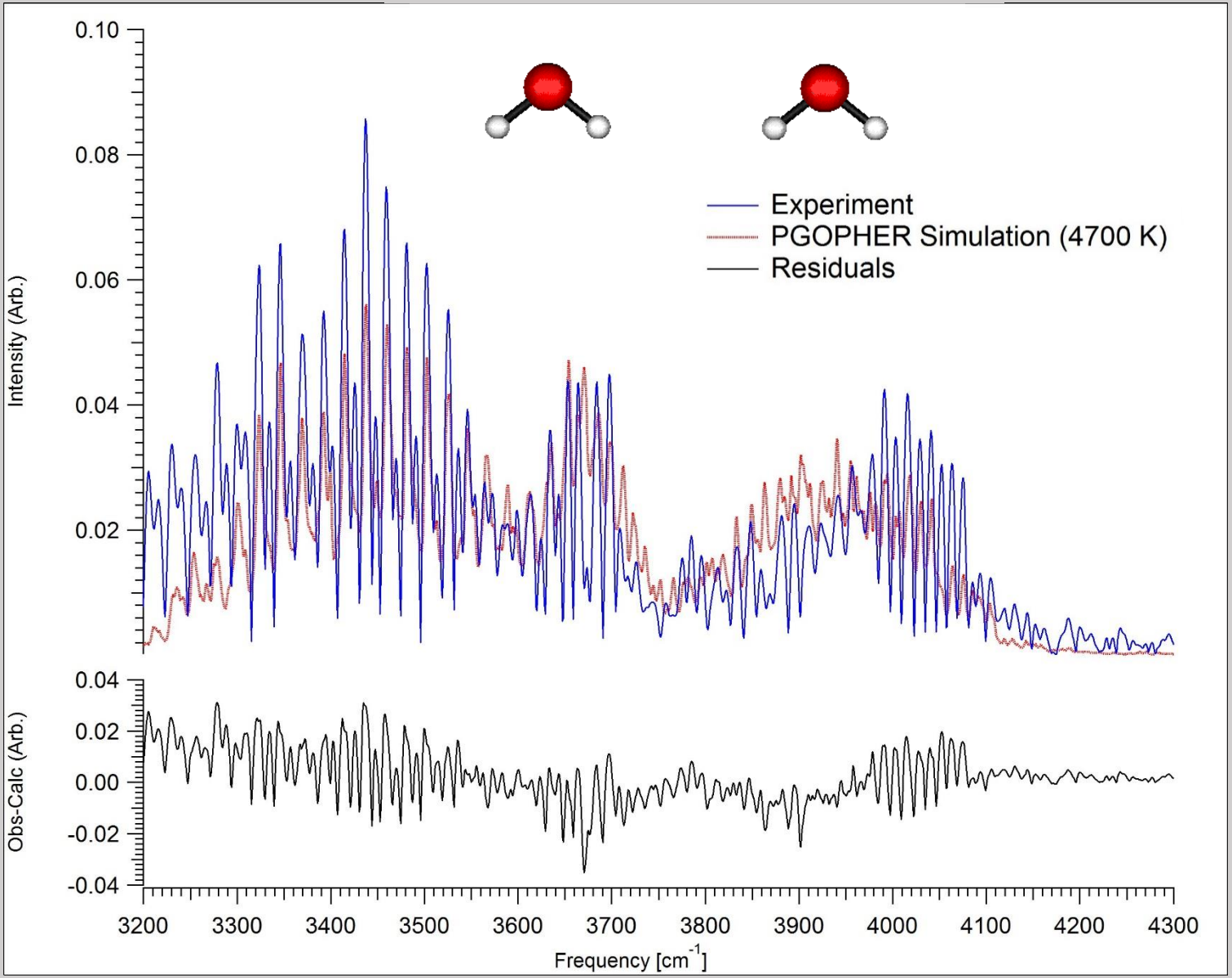
Dubowsky et. al; *J. Mol. Spec.*, **2015**, Submitted.

Results



Dubowsky et. al; *J. Mol. Spec.*, **2015**, Submitted.

Fitting



PGOPHER, a Program for Simulating Rotational Structure, C. M. Western, University of Bristol, http://pgopher.chm.bris.ac.uk

Rothman et al. *Journal of Quantitative Spectroscopy & Radiative Transfer,* **2013**, *130*, 4

Dubowsky et. al; *J. Mol. Spec.*, **2015**, Submitted.

http://www2.ess.ucla.edu/~schauble/MoleculeHTML/H2O_html/H2O_page.html

Rotational Temperatures

Shot	$T_{H_2O}^{stretch}$	$T_{H_2O}^{bend}$	T_{OH}
1	5140	3950	6700
2	7190	6160	6900
3	3550	3280	N/A*
4	4730	2390	9200
5	7240	3670	7500
Average	5600 ± 1300	3990 ± 900	7600 ± 800

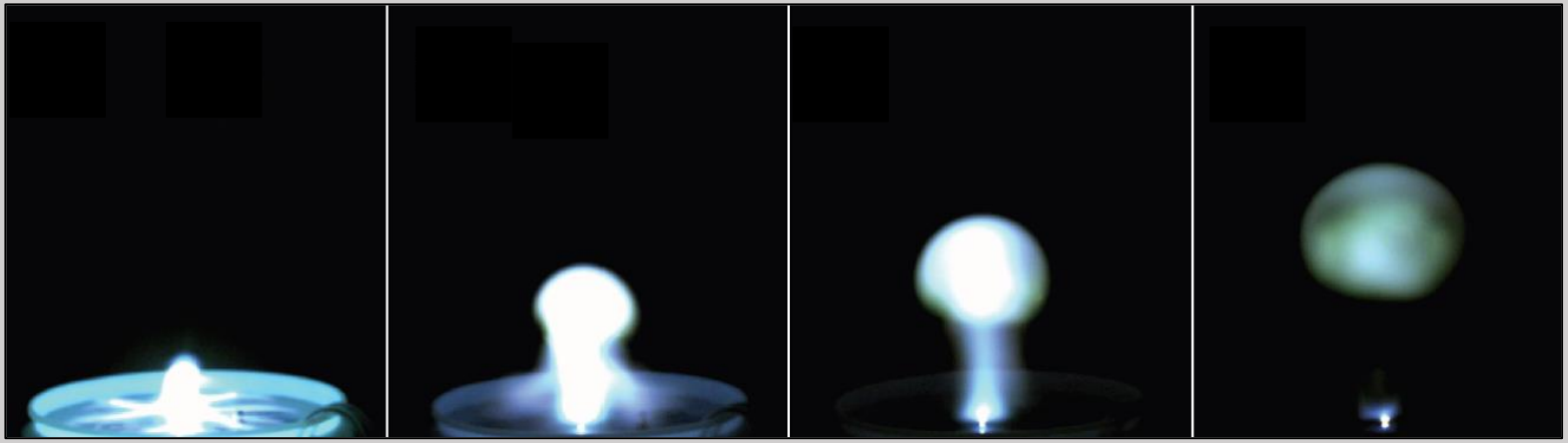
*Lineshapes result in fits not converging

- Differences between vibrational bands of water
  - Plasma dynamics
- Hydroxyl: comparable to literature (15,000 K)

Dubowsky et. al; *J. Mol. Spec.*, **2015**, Submitted.

Summary

- Lab analogue of ball lightning
  - High voltage, water-based discharge
  - Three distinct phases, most interested in detachment
- Mass Spectrometry
- Emission spectroscopy
- Young experiment



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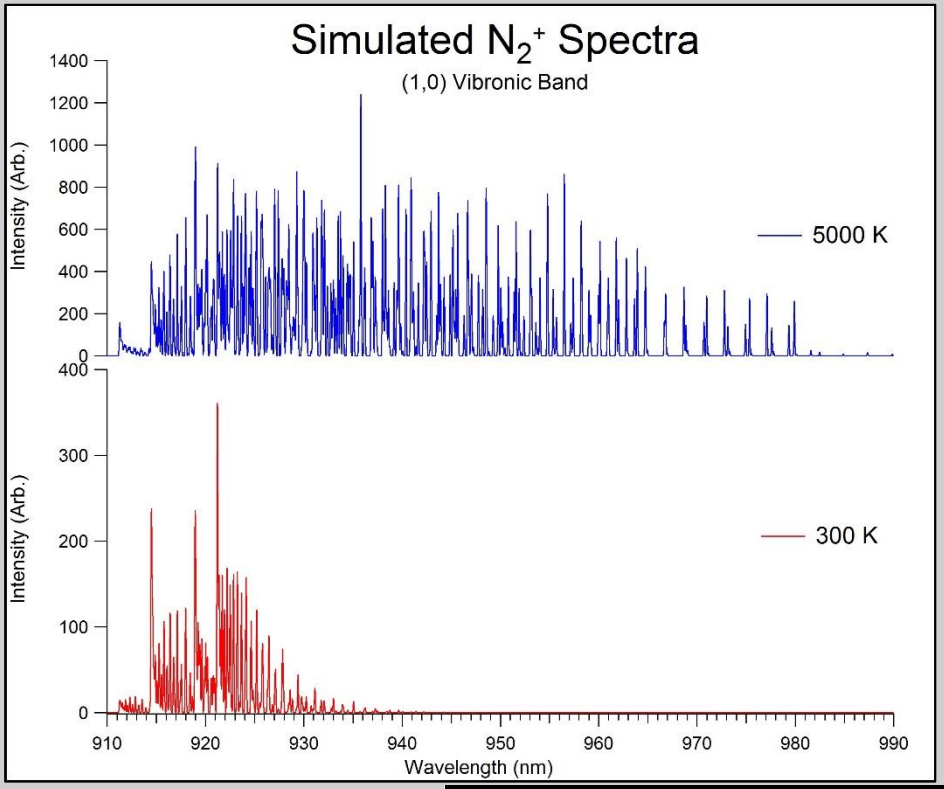
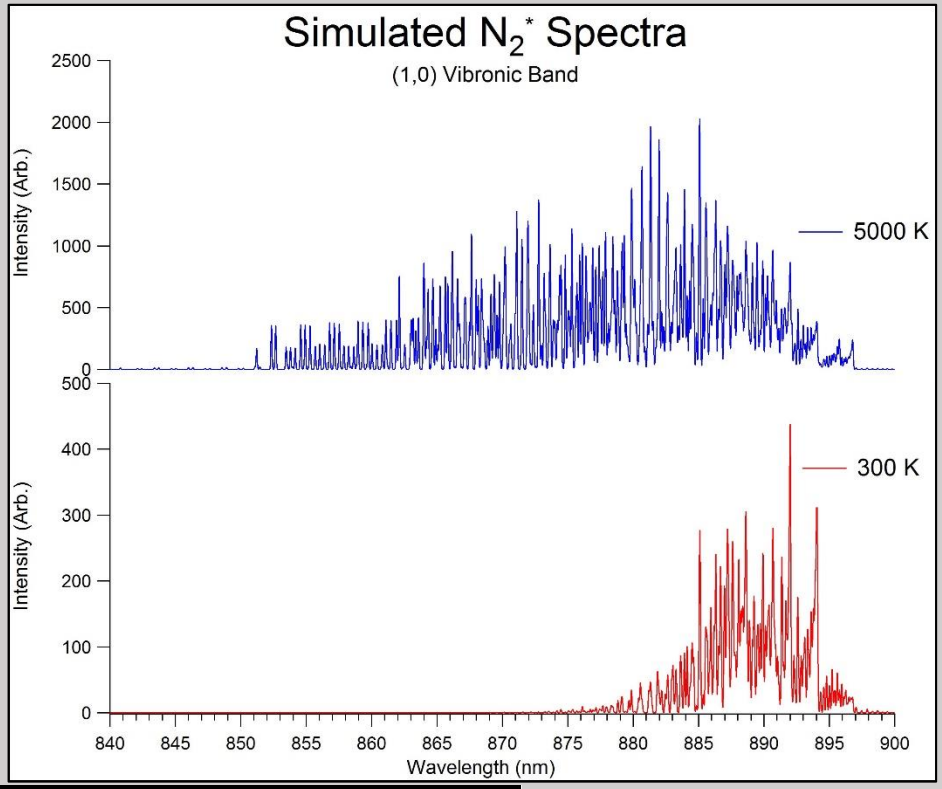
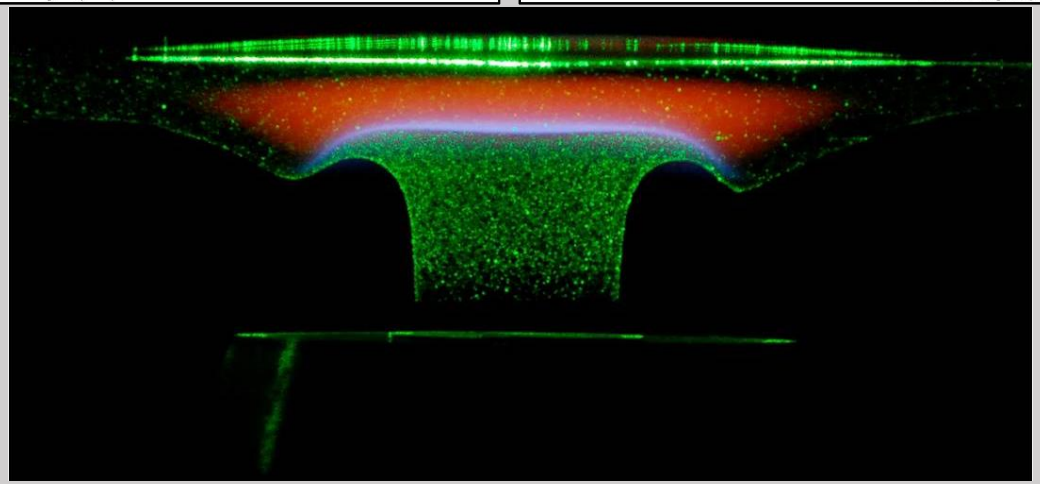
Future Directions

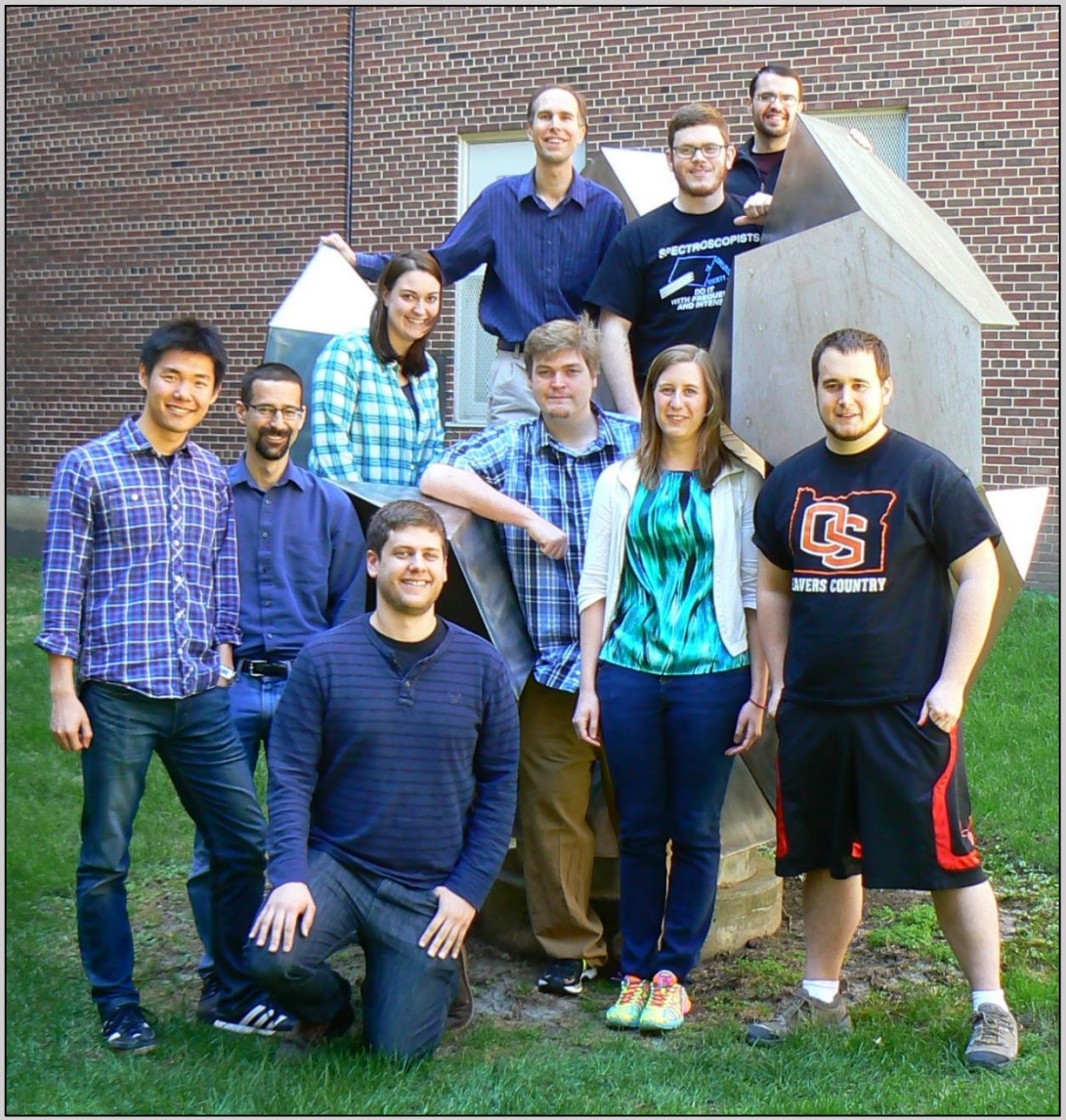






https://en.wikipedia.org/wiki/Particle_image_velocimetry

Acknowledgements



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