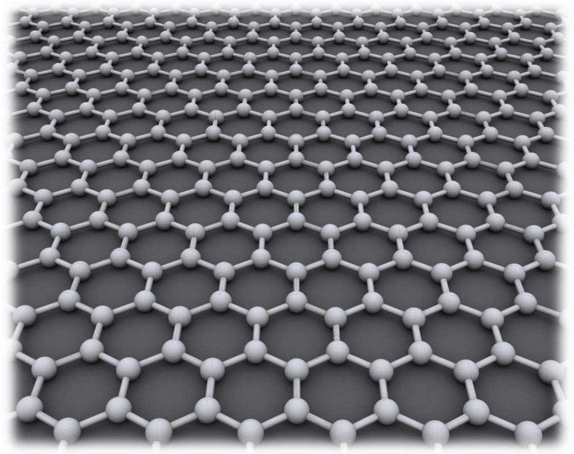
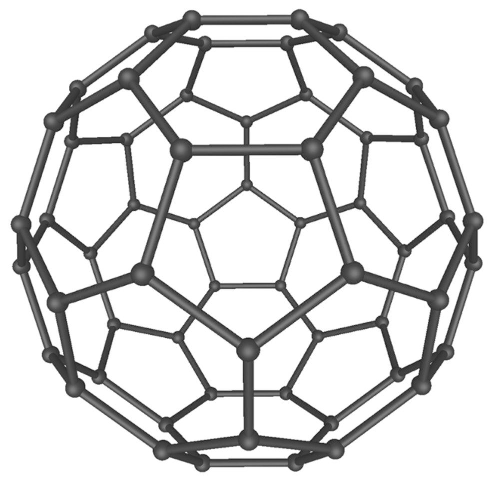
Density Measurements of a Carbon Arc Using Stark Spectroscopy

Daniel Cashon-Smith, *University of Washington*
Advised by: V. Vekselman, *PPPL*

Abstract & Motivations

A DC arc discharge between two carbon electrodes with the addition of metal catalysts has been shown to produce carbon nanomaterials such as carbon nanotubes and fullerenes[1].





Currently, the physics of carbon arc discharges are not well understood. The unique material properties and applications of these nanomaterials motivate research into how the behavior of the carbon arc affects carbon nanosynthesis. Here, a non-invasive plasma diagnostic technique know as Stark spectroscopy is used to measure the density and temperature of a carbon arc.

Theory

A small amount of hydrogen is included in the buffer gas to facilitate measurement of the spectral line profile of Hα. This takes the form of a Voigt profile:

$$V(\lambda) = [G \otimes L](\lambda)$$

The observed profile is a convolution of Gaussian and Lorentzian profiles dominated by:

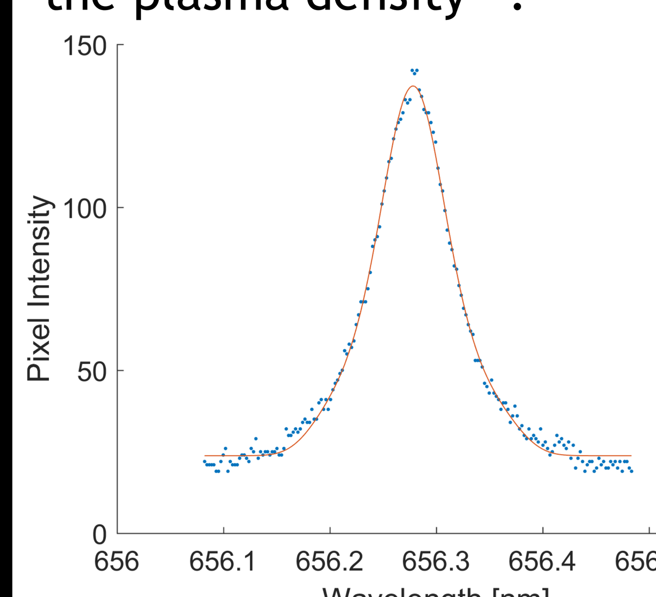
$\Delta\lambda_D =$ Doppler effect broadening

$\Delta\lambda_I =$ Instrumental broadening

$\Delta\lambda_{Waals} =$ Van der Waals broadening

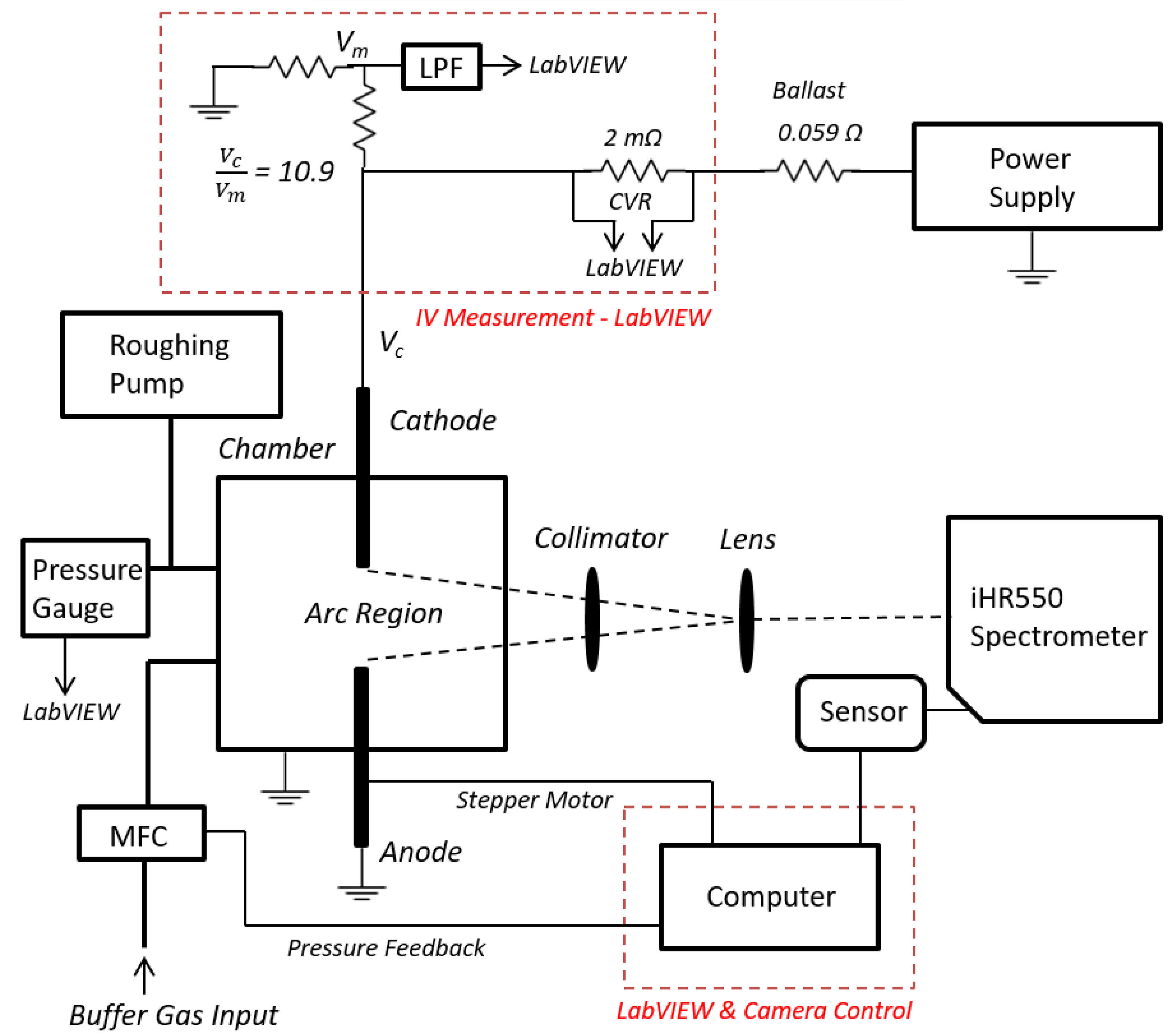
$\Delta\lambda_S =$ Stark effect broadening dependent on plasma density

An appropriate Voigt profile can be fit to experimental data to extract the Stark broadening component, which can be related to the plasma density[3].



$\rightarrow \Delta\lambda_S \rightarrow n_e$ Radial density profile is obtained at a given arc cross section

Experimental Setup



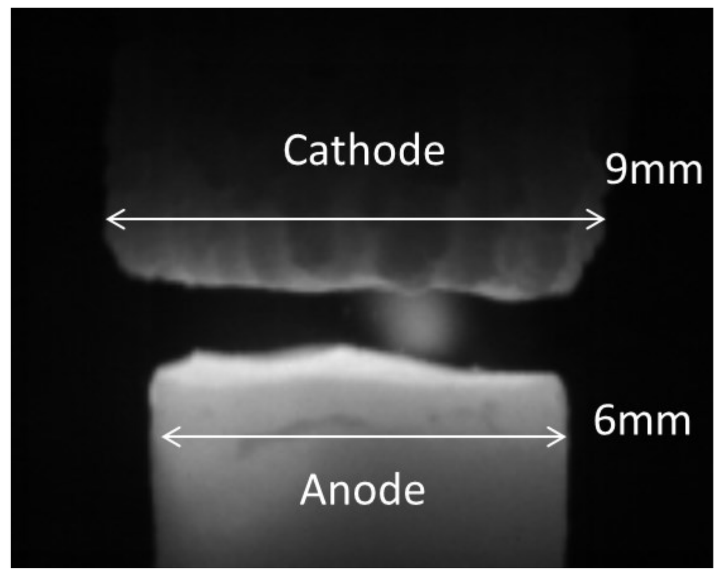
Testing

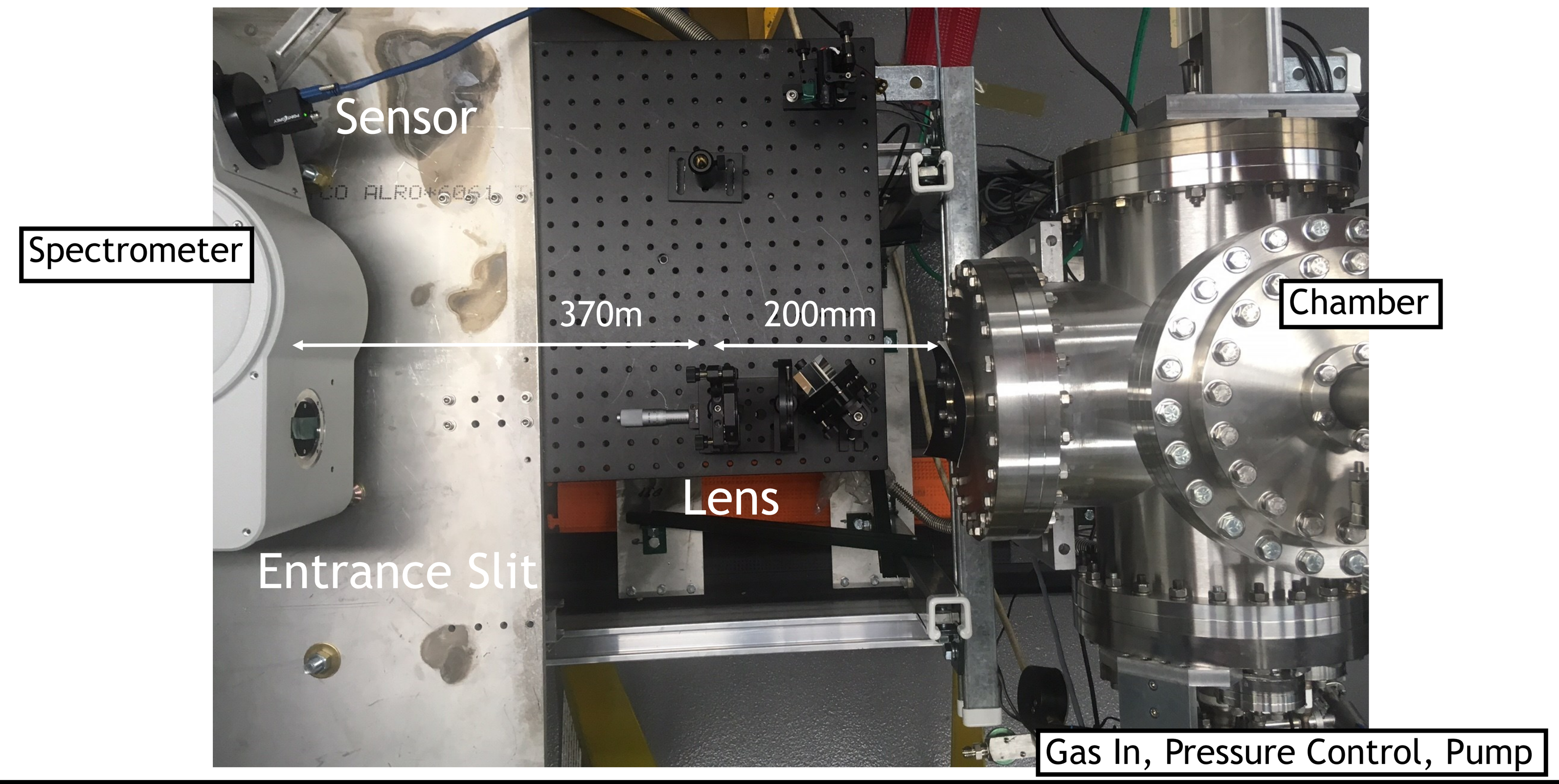
Fixed Experimental Parameters:

- Chamber Pressure: 500 Torr
- Arc Current: ~50A
- Arc Voltage: ~27V
- Buffer Gas: He-H mix (5% H by mole)

Spectrometer Calibration:

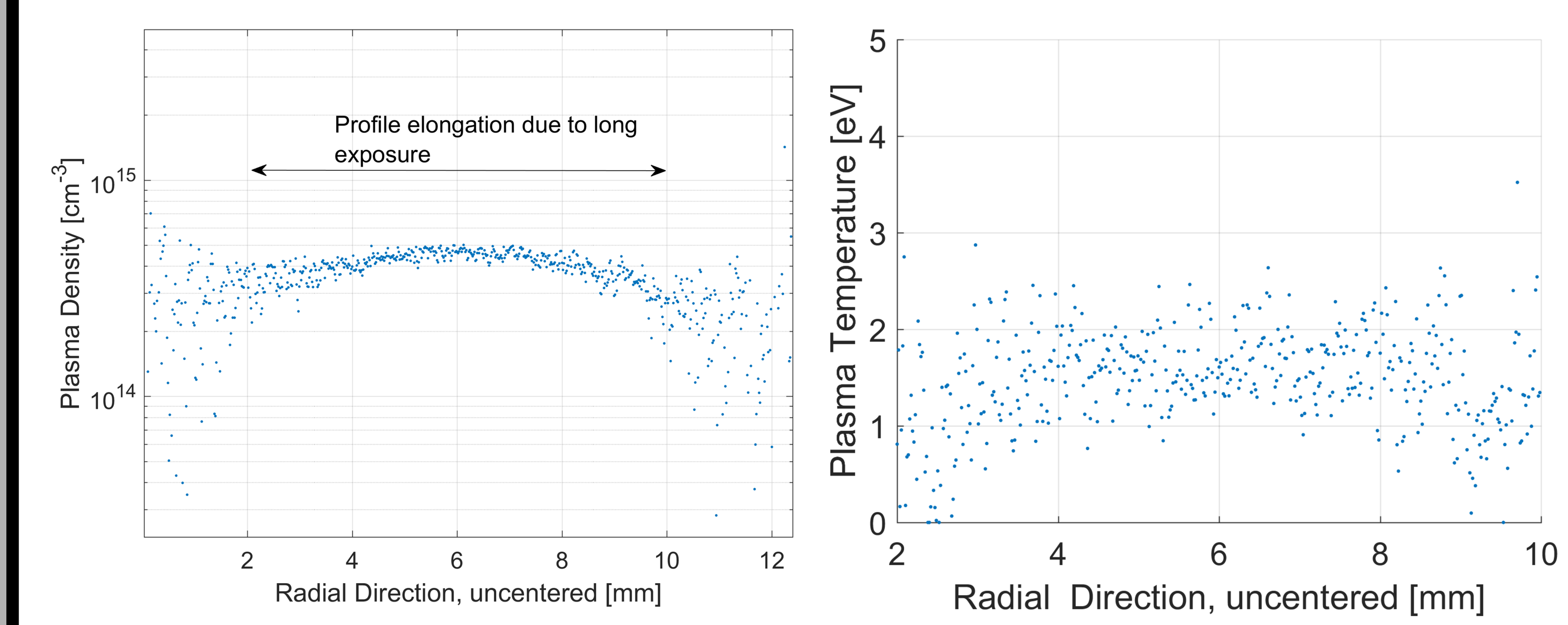
- Spectral Dispersion: ~456 pix/nm
- Spatial Resolution: ~0.0065 mm/pix





Results

The fast dynamics of the carbon arc plasma in question make application of spectroscopy difficult. The use of a 0.8 ms exposure time (hardware limitation) was found to be too slow to resolve an accurate radial density profile. Instead, data is time averaged as the arc moves significantly over the duration of the exposure time. Nor do these results include the effect of Van der Waals broadening, which is not negligible. However, a rough estimate of arc core density and temperature can still be obtained. Data presented is from a single frame of arc operated at approximately 52A.



Arc Density at Core: 10^{14} to 10^{15} [cm^{-3}]

Arc Temperature at Core: 1 to 2 [eV]

Conclusions & Future Work

Implementation of Stark spectroscopy yielded estimates of the arc core density and temperature in fair agreement with previous results[1]. The difficulty of accurately fitting and deconvolving the Voigt profile and dealing with fast time-scale arc motion should not be overlooked. With this method, it should be possible to obtain a full radial profile of temperature and density as a function of position along the arc dimension, leading to 2-D temperature and density maps. Future work should expand on accurate Voigt profile fitting and deconvolution methods, along with further examination into the outer regions of the arc where nanosynthesis is expected to occur[1].

References

[1] V. Vekselman , M. Feurer, T. Huang, B. Stratton and Y. Raitses, **"Complex structure of the carbon arc discharge for synthesis of nanotubes"**, *Plasma Sources Sci. T.* ***26***, *065019 (2017)*

[2] G. Vogman, **"Deconvolution of Spectral Voigt Profiles Using Inverse Methods and Fourier Trans forms"**, *Senior Thesis, June 2010*

[3] U. Fantz, **"Basics of Plasma Spectroscopy"**, *Plasma Sources Sci. T.* ***15***, *S137 (2006)*

[4] Zhou Qiuping *et al.*, **"Electron Density and Temperature Measurement by Stark Broadening in a Cold Argon Arc-Plasma Jet at Atmospheric Pressure"**, *Plasma Sci. Technol.* ***11***, *560 (2009)*

Acknowledgements

I'd like to thank Vlad Vekselman for his valuable insight and assistance, and also the rest of the members of the Laboratory for Plasma Nanosynthesis at PPPL. This work was supported by the U.S. Department of Energy SULI internship program.