SAND2011-5304C

SAND2011-5304 C

Arc generation and plasma transport

Presentation to:

MEV
June 28, 2011

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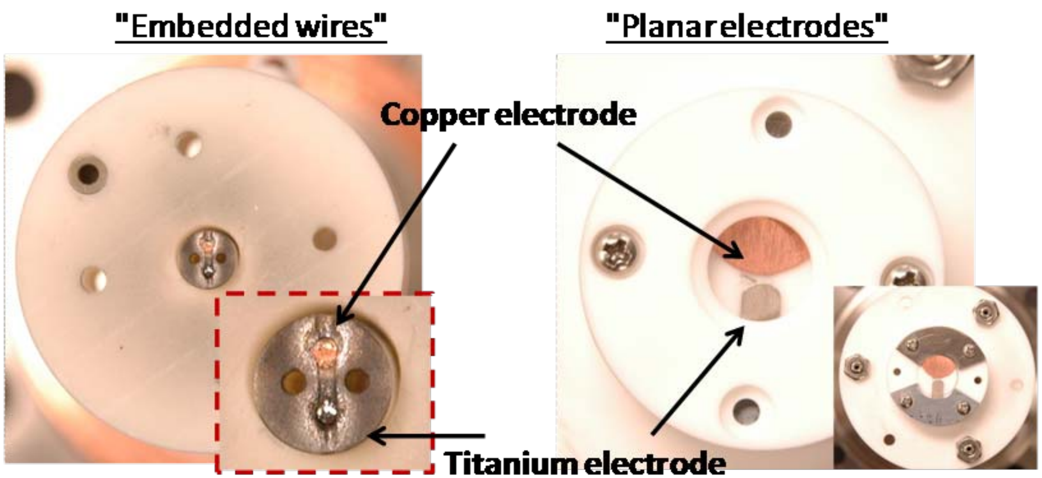
Introduction to the types of arcs we are considering

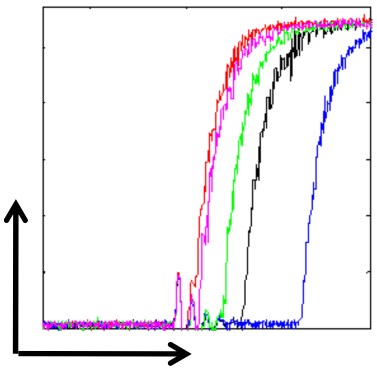
- Experiments need to be flexible and versatile
  - Test predictive capabilities of code
  - Target desired physics
  - Overcome intrinsic headaches associated with arcs
- Co-planar two electrode metal arcs embedded in ceramic sleeves
  - Various configurations and compositions
  - Mostly vacuum, but not always



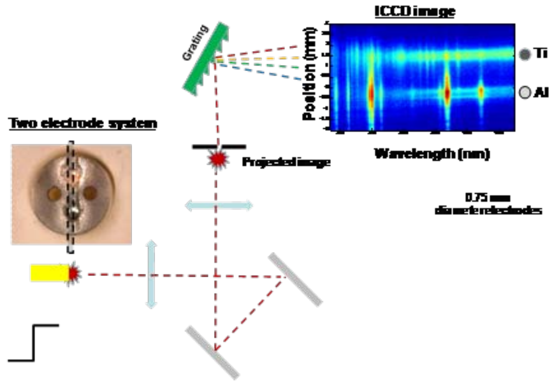
A wide range of diagnostic techniques are needed to study arc physics

- A wide range of techniques can be utilized to probe aspects of plasma generated in an arc
  - Our challenge is to match the right tool to the right job
- Tools can consist of
  - "Global" current and voltage
  - Semi-localized optical emission and ion beam spectroscopies
  - Localized laser induced fluorescence and or scattering

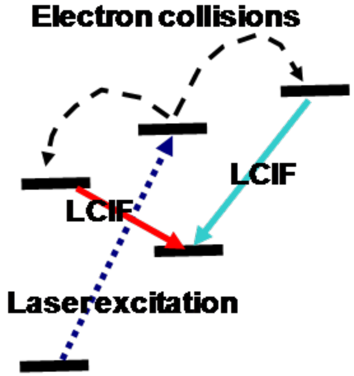
Current trends



Optical emission



Laser spectroscopy



Demonstration of various tools and techniques we employ

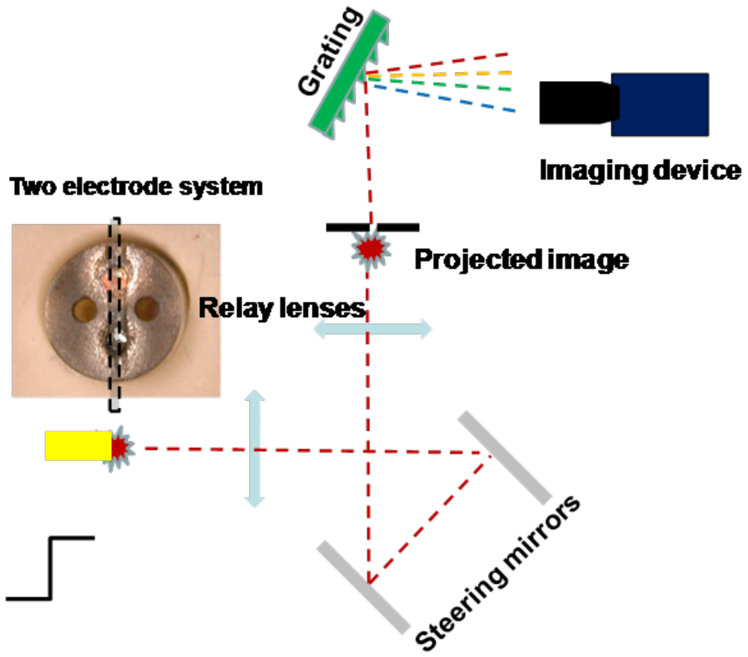
Diagnostic methods to identify species present in the arc

- Central questions include
  - What is present in the arc?
  - When is it generated?
  - Where is it generated from?
  - What are these species properties (energies and densities)?
- Answers to these questions help us understand
  - Phenomena or arc generation
  - Plasma transport
- Various diagnostics are utilized to address these questions

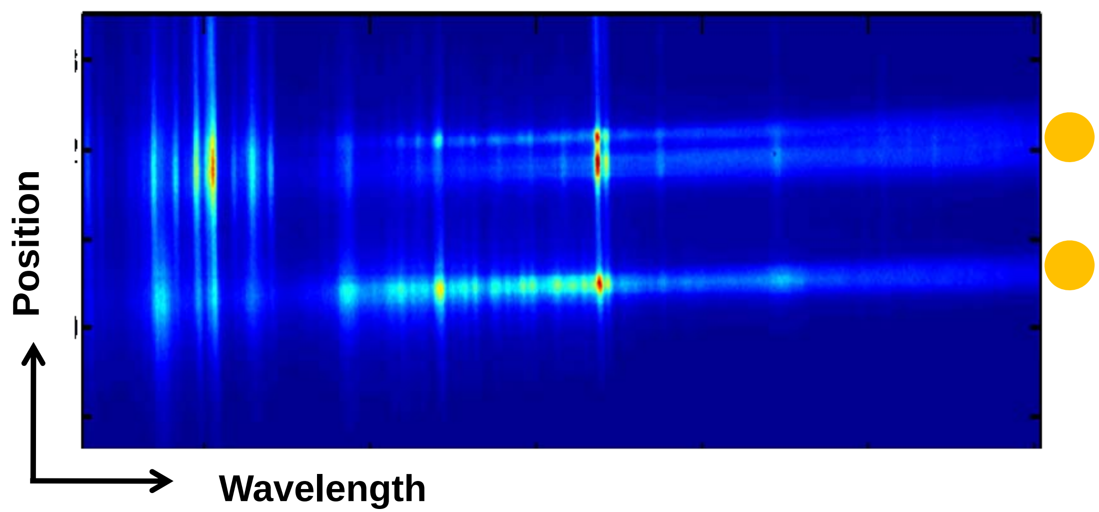
Optical emission spectroscopy is obvious choice for arc diagnostics

- Light from the plasma is plentiful and easily detectable
  - Look for unique signatures associated with species in the plasma
- Imaging spectrometers and CCD devices to capture both spatiall and spectral trends

Setup

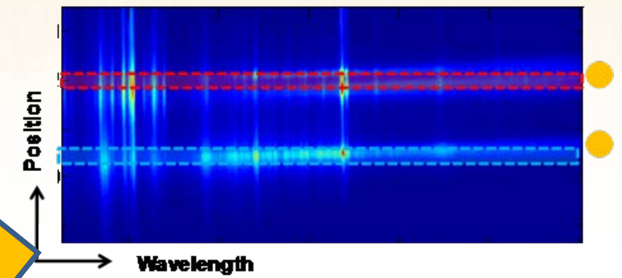


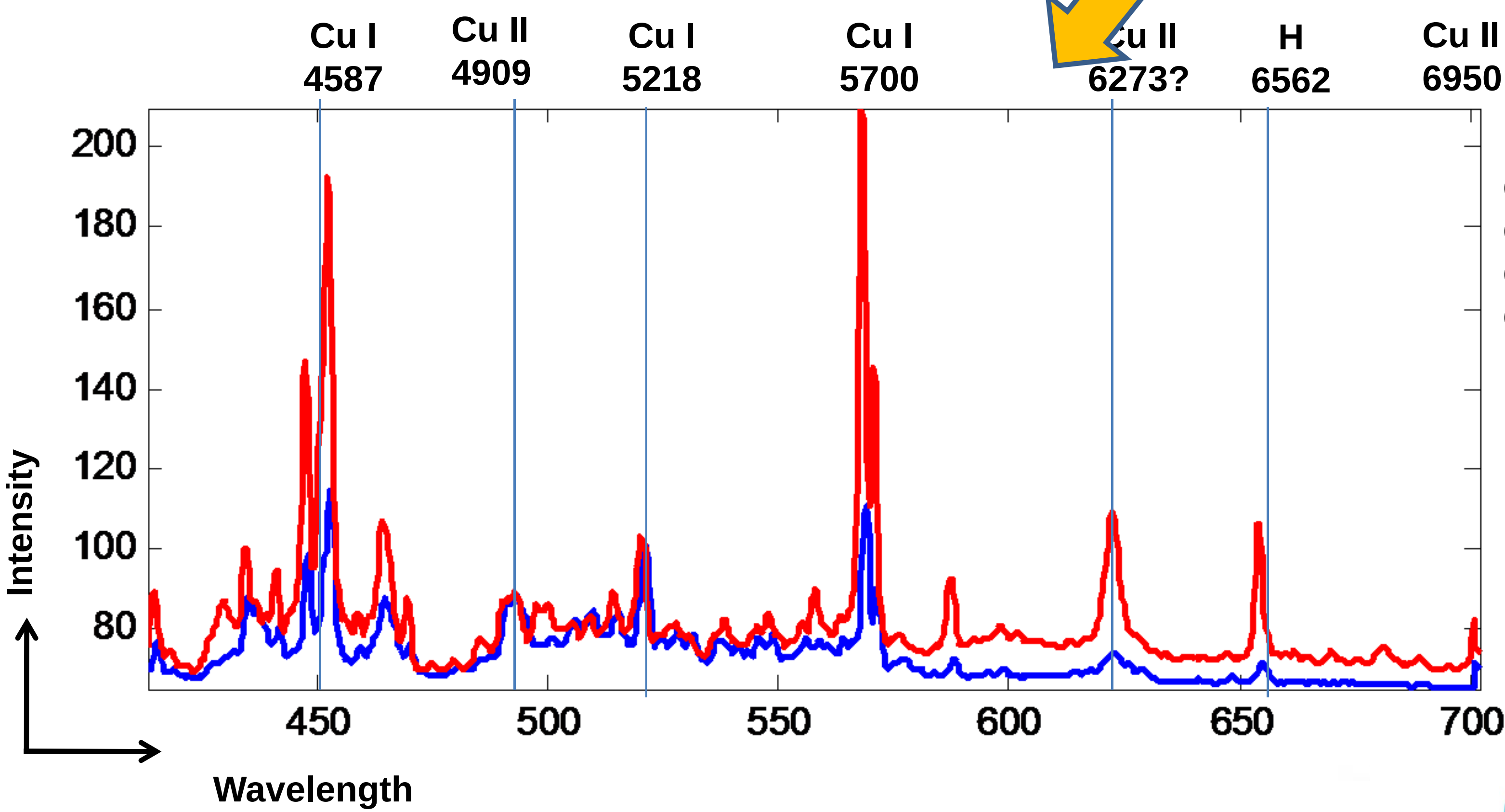
Representative data



Broad band spectral data is acquired for a Cu-Cu arc

- Analysis of acquired image yields
  - what type of species are generated
  - where they are generated





Cu I - 18 lines
Cu II - 120 lines
Cu III - 31 lines
Cu IV - ?

+

-

By far….. Dominant species is Cu I - neutral copper….

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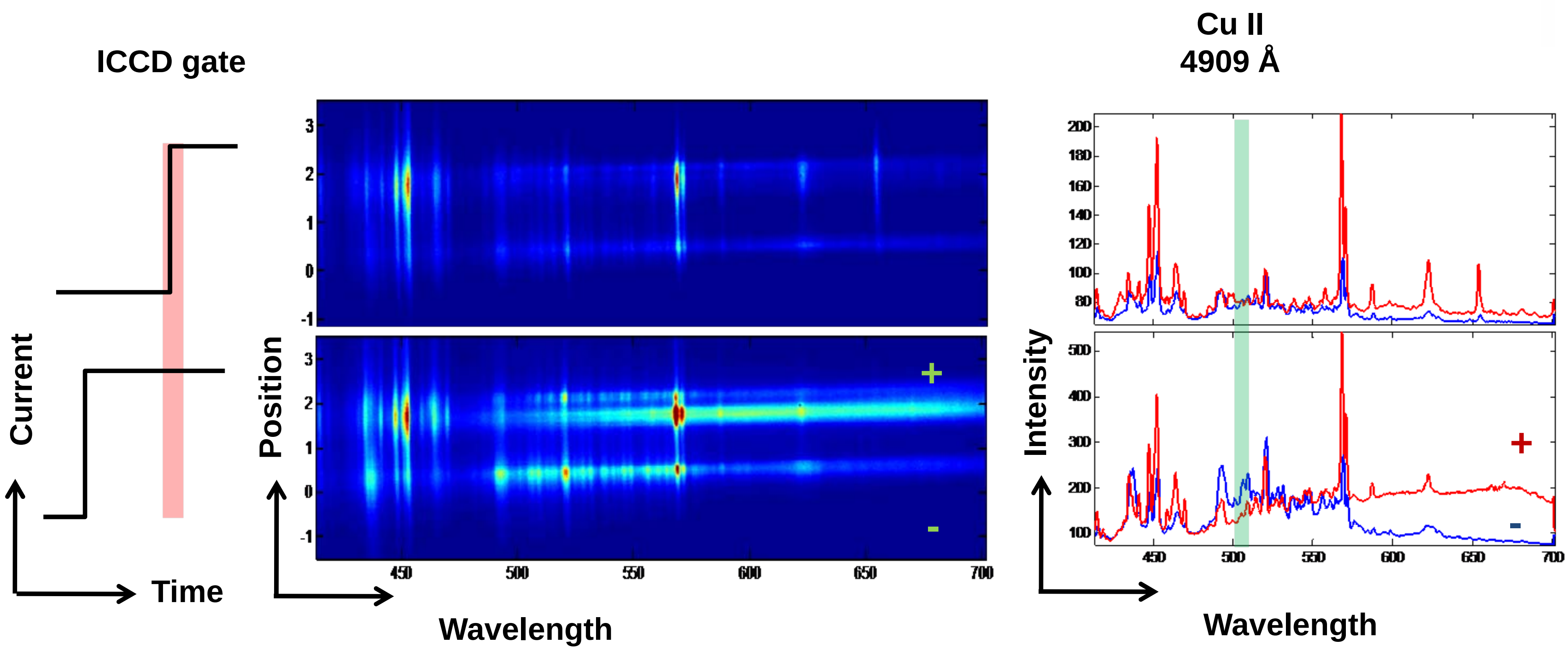
Further information is gained be watching spectral evolution over time

- Acquire spectral data over evolution of the arc
  - Gated, intensified camera sychronized to firing of the arc

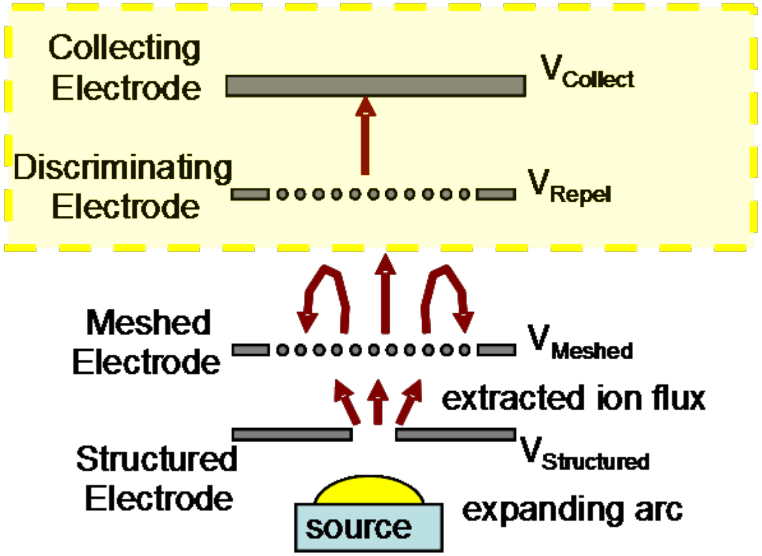


Emission from the arc is dynamic event

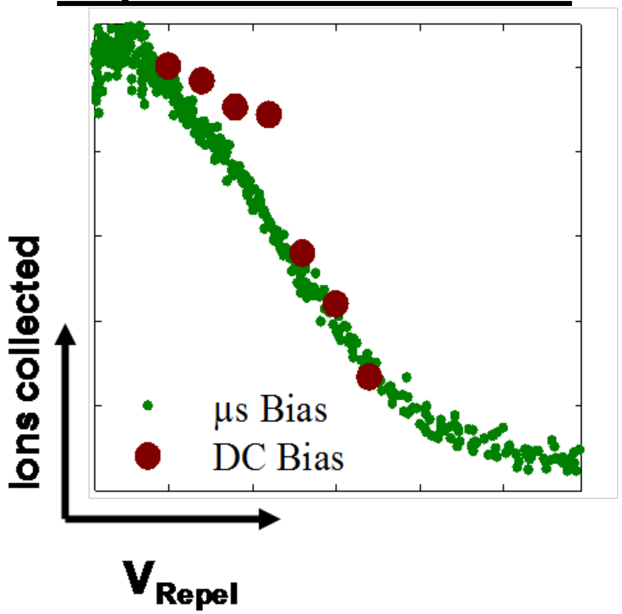
Energy distribution characterized by Retarding Field Energy Analyzer

- Attempt to quantify velocity distribution of ions from arc
  - Discrimination of ions via energy
- Two pronged approach
  - Fixed DC voltage -> "Time resolved" energy discrimination
  - Pulsed or swept voltage -> "quasi-instantaneous" energy interrogation

Concept



Representative results

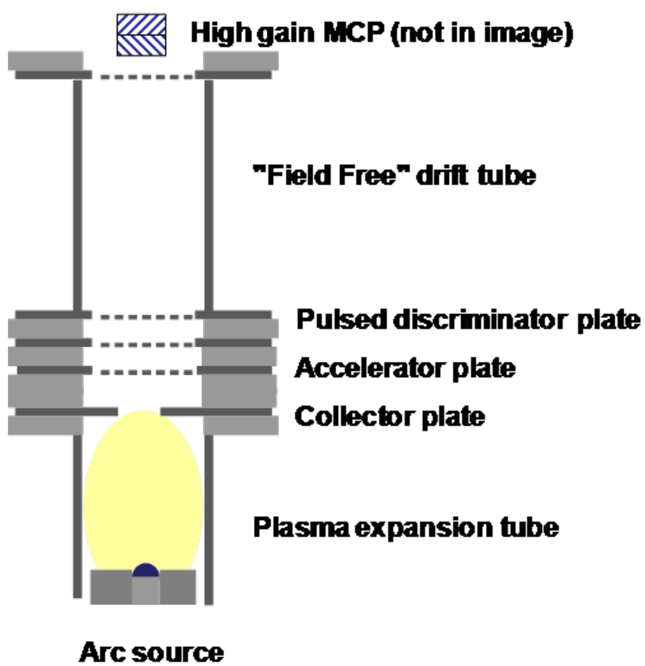


Technique resolves total energy distribution, but can not differentiate individual species

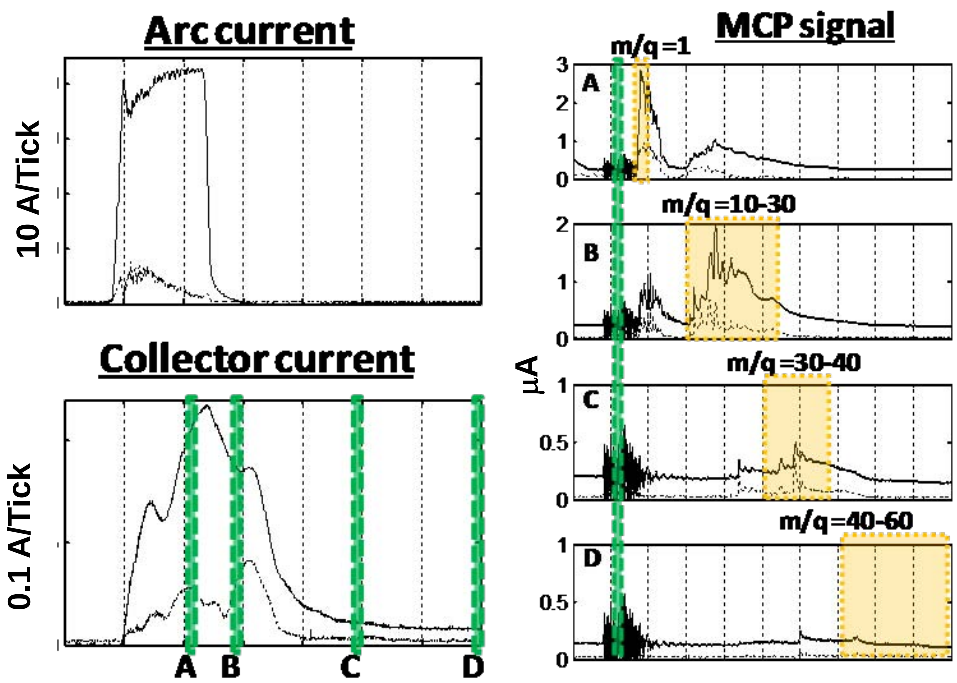
Time of flight techniques are used to examine ion beam composition

- TOF based techniques can be used to assay plasma composition
  - Gate injection to sample plasma

Setup



Representative results

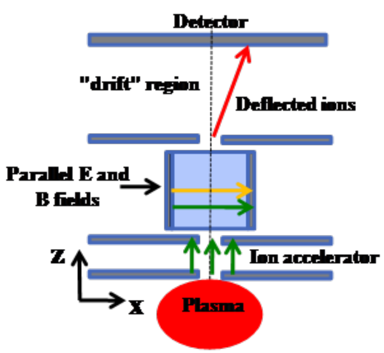


Provides semi-quantitative data, becomes difficult to separate heavier masses

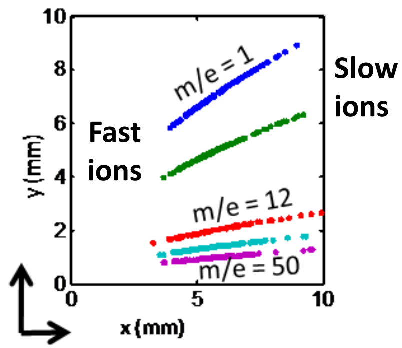
Thompson spectrometer offers ability to measure both mass and energy

- Differentially deflect ions based on energy and momentum

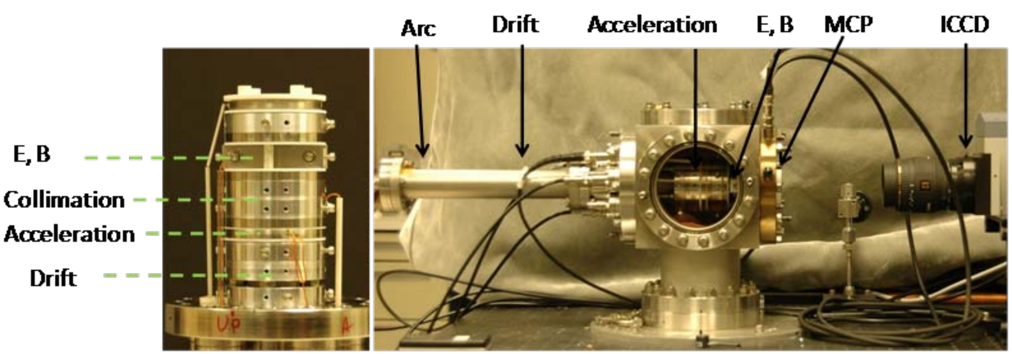
Principle of operation



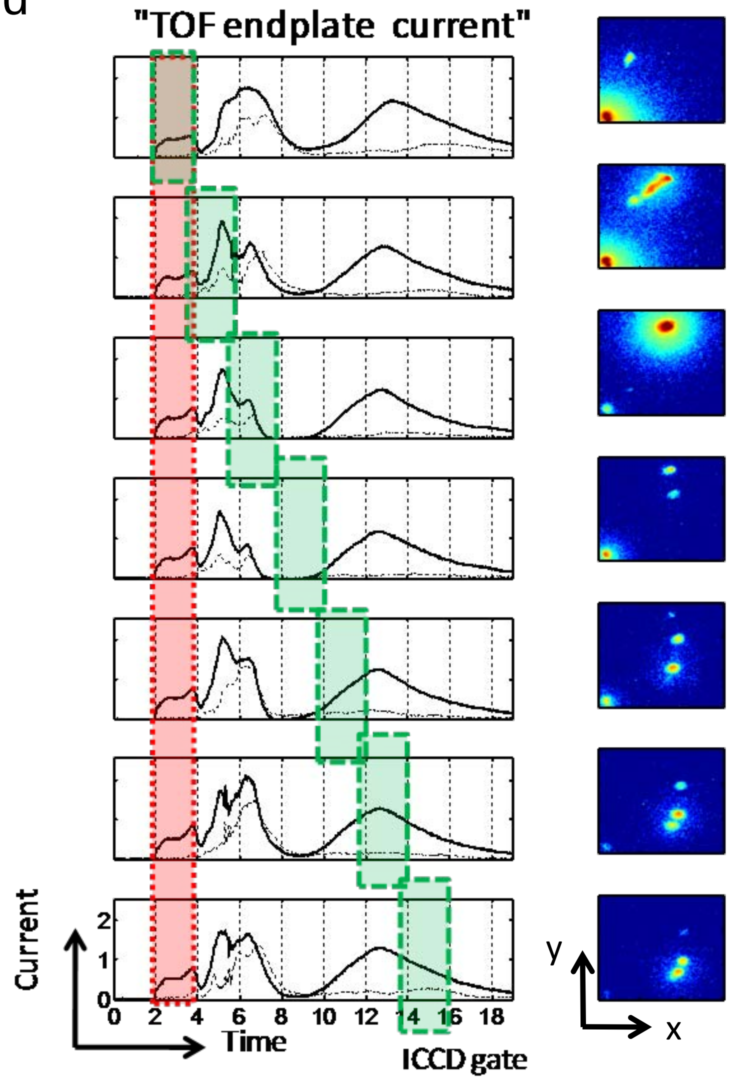
Predicted behavior



Setup

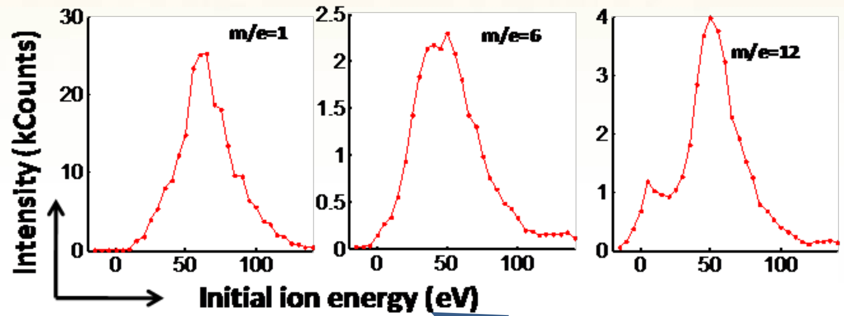


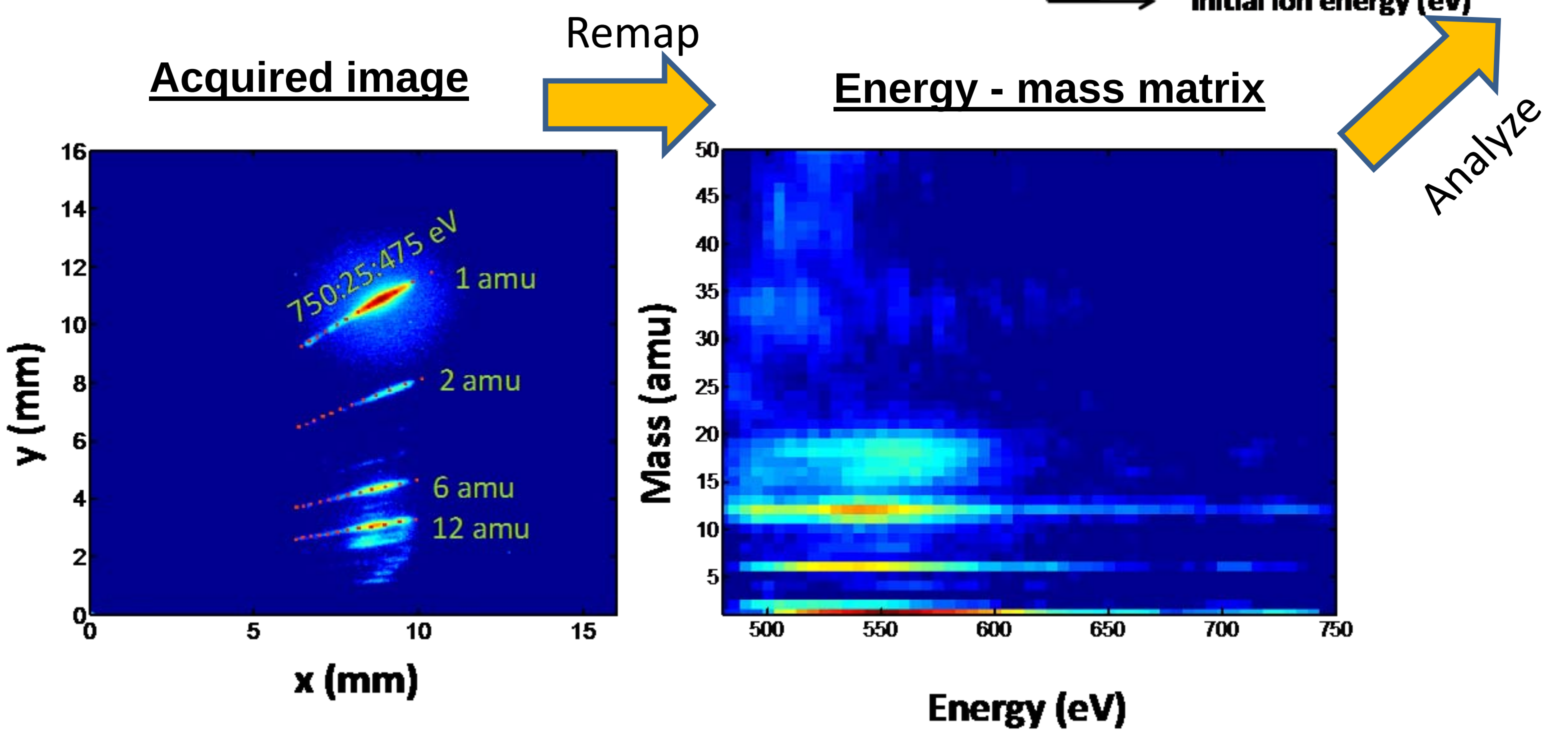
Representative results



Quantitative energy distributions obtained with Thomson spectrometer

- Refined technique, developed analysis
  - Produce energy distribution





Analysis provides energy distribution for individual m/e species

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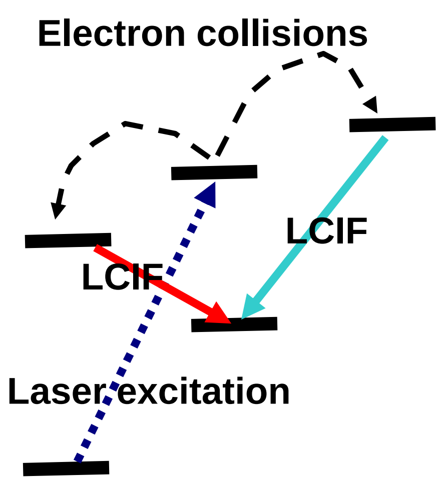
Diagnostic methods to quantify electron densities and electron temperatures in the arc

- Electrons are critical to behavior of the arc
  - "Work horse"
  - Ionize species
  - Mediate plasma transport
- Implement diagnostics to quantify the dynamics of electrons in the plasma environment

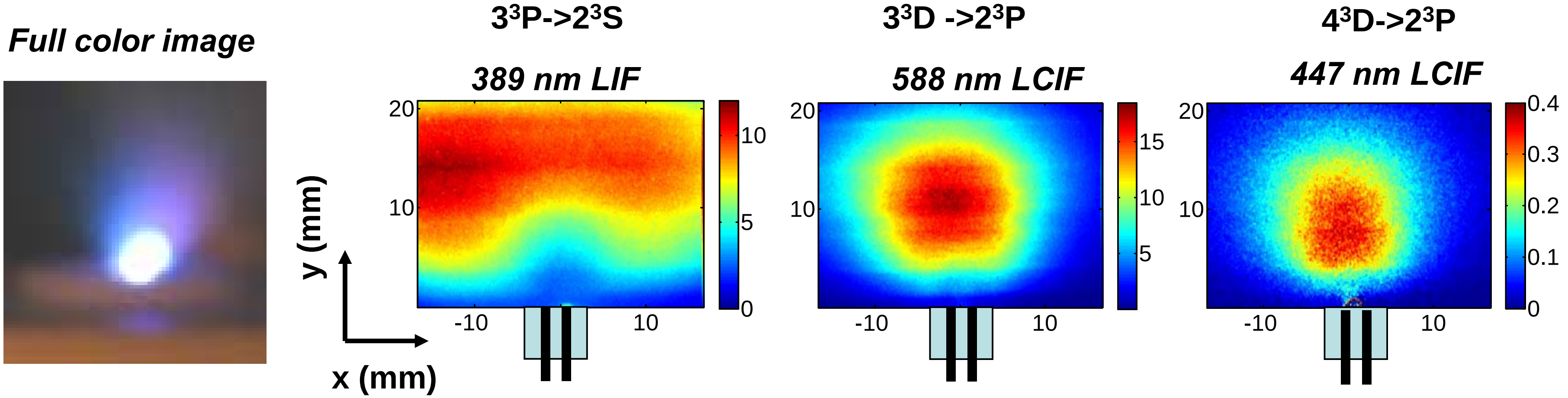
LCIF is investigated to fill in the blanks

- LCIF: Laser-collision induced fluorescence
  - Electrons re-allocate laser populated states
- Rate equations solved to predict where population goes
  - Need to know electron impact cross sections
  - Collisional-radiative model computes response
- Technique described and published in open literature
  - E.V. Barnat and K Frederickson, Plasma Sourc. Sci. Technol. **19**, 055015 (2010)

Concept



Application



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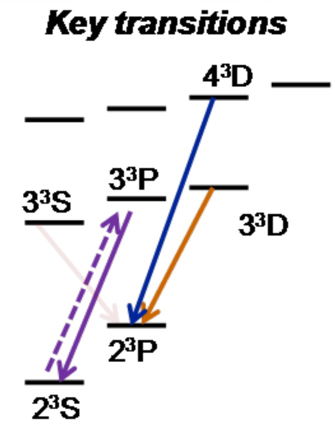
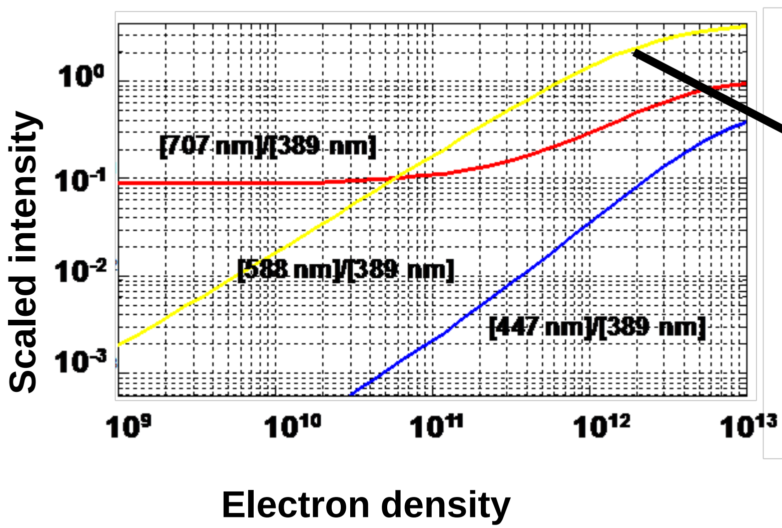
LCIF works quite well over broad density range

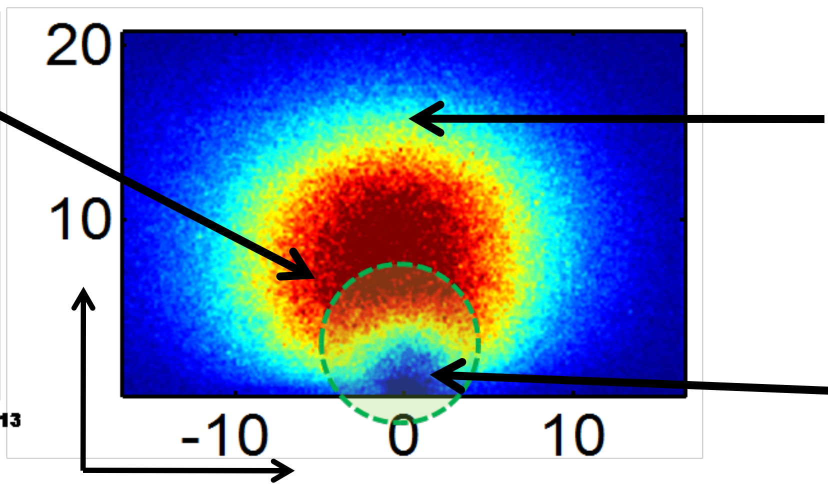
- In general ratio of 589 nm (3^3D) to 388 nm (3^3P) is linear over 3 orders of density
  - Temperature insensitive
- At densities of 10^{13} electrons/cm^3, linearity breaks down



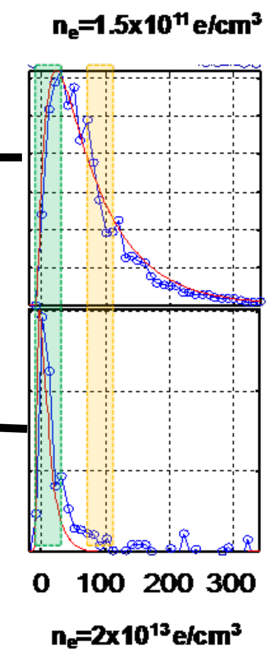
CRM trends



Measured profile



Temporal signature



Need to use metric more clever than linearity to back out densities above ~10^{12}

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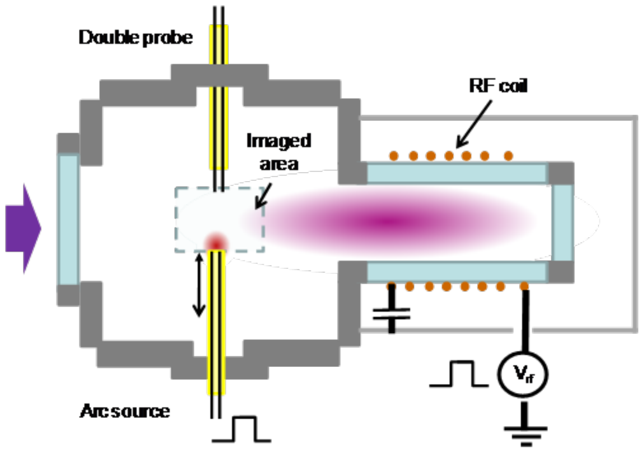
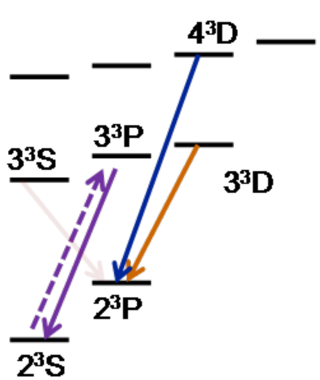
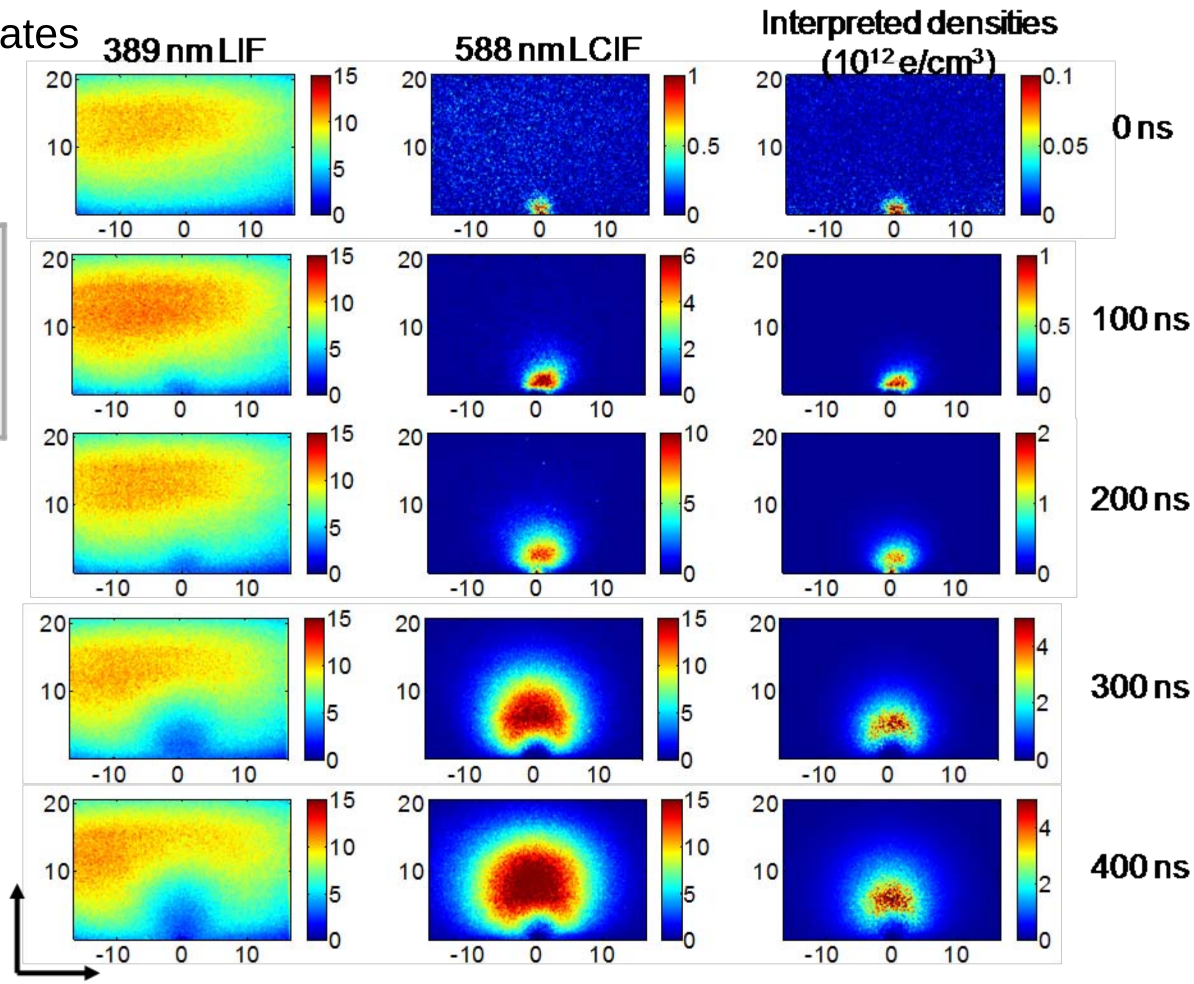
LCIF captures arc generation and expansion

- **Examine generation of arc**
  - Low pressure (30 mTorr) helium after glow
  - Time steps of 100 ns, 50 ns gates



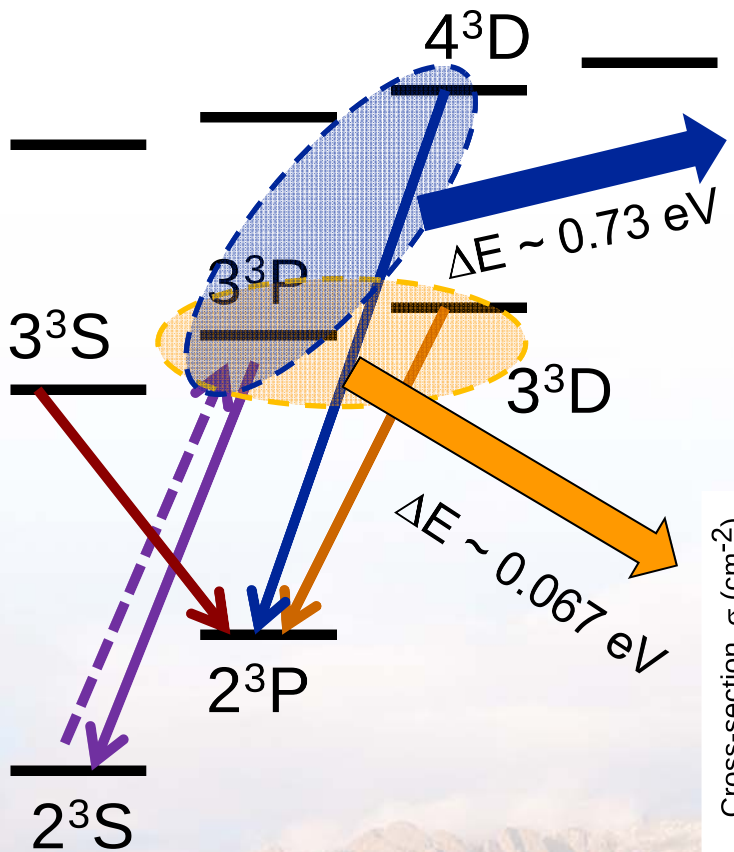
Key transitions

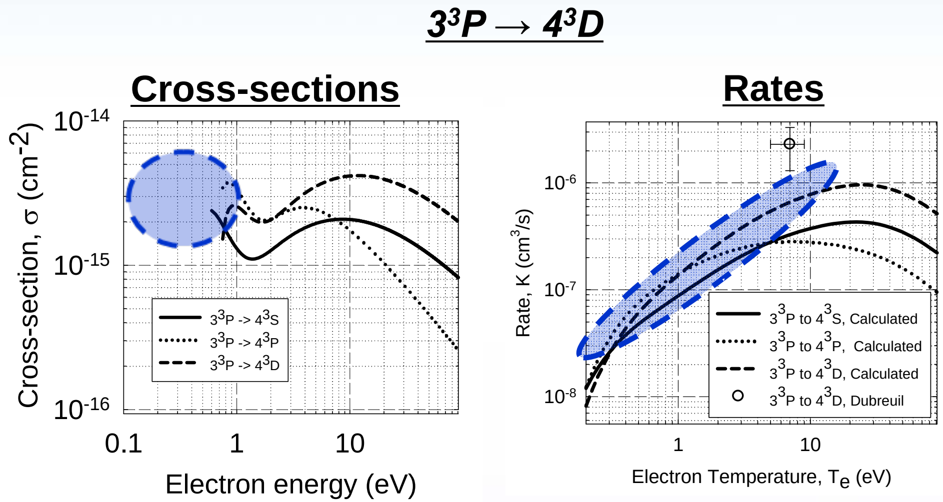


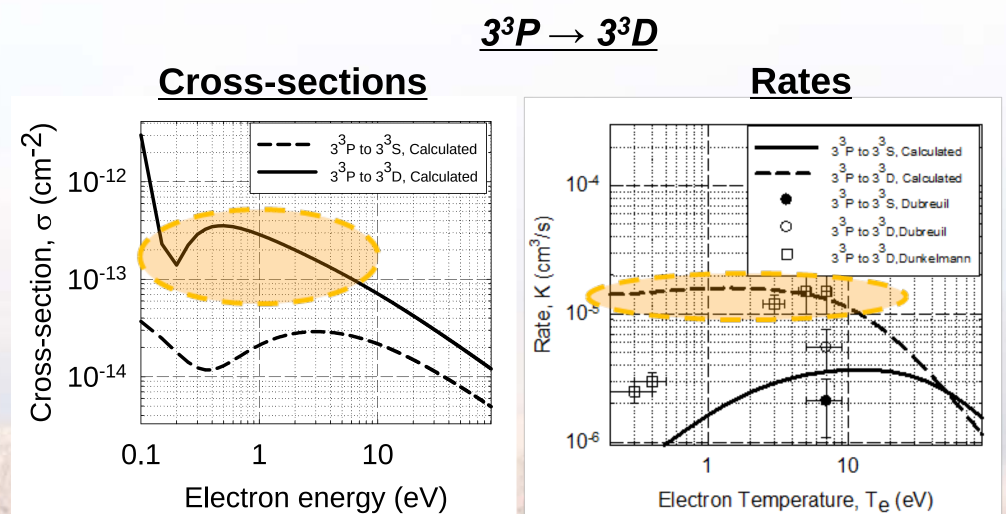


Spatial-temporal maps of arc expansion

Monitoring higher levels gives measure of "electron temperature"







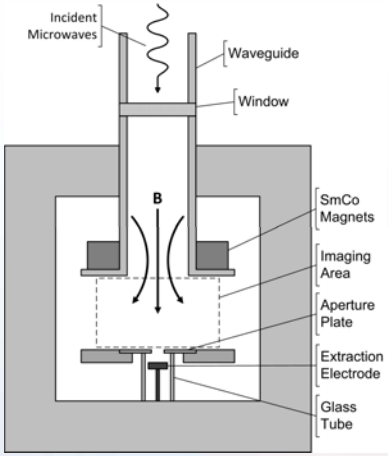
This is a work in progress and quite sensitive to functional forms of rates

Yu. Ralchenko, R. K. Janev, T. Kato, D. V. Fursa, I. Bray, F. J. De Heer, Atomic Data and Nuclear Data Tables **94**, 603 (2008)

Temperature measurements have been difficult in the arc

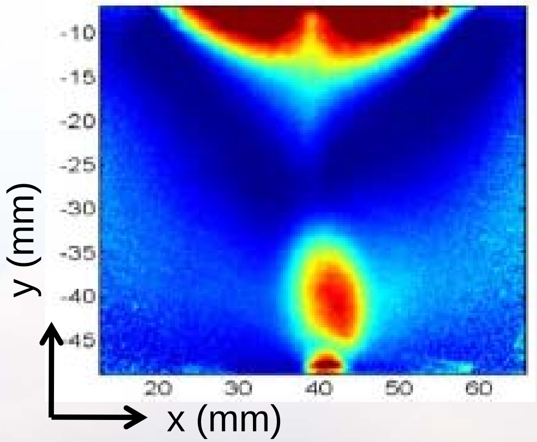
- **Electron temperature concept has been employed in other plasma systems**
  - ECR generated plasma cathode experiments
  - NASA driven research interested in electron sources for ion propulsion neutralization

Setup

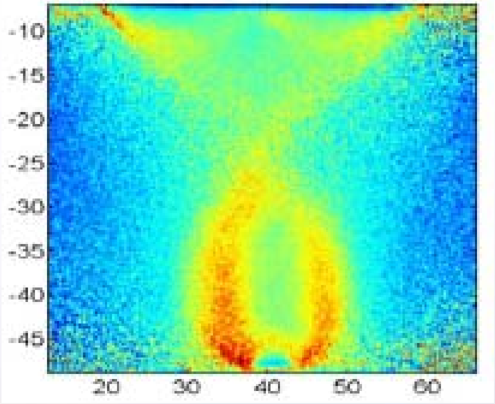


"Full color" picture

Density



Temperature

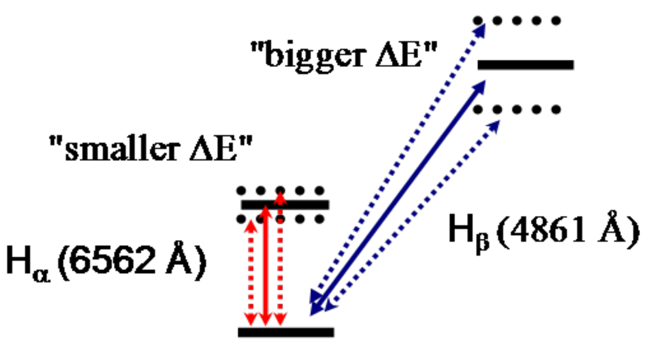


Regions of adjacent plasmas are mediated by electric fields that induce higher electron temperatures

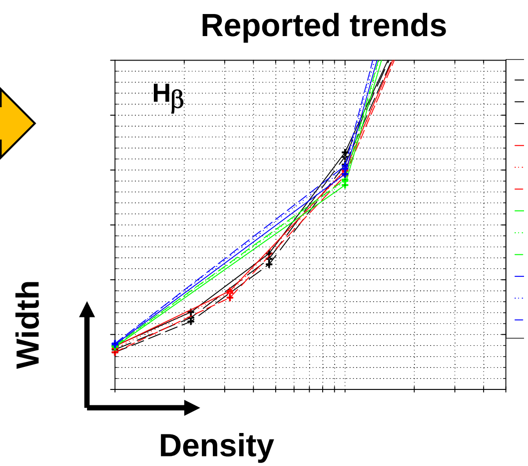
Stark broadening is used to target higher densities

- Electrons and ions "perturb" atomic orbitals
  - Degree of interaction ~ n_e and T_e
- Measured profiles are convolution
  - Stark, Van der Waals, Doppler and Instrument
- Fit profiles to obtain n_e,

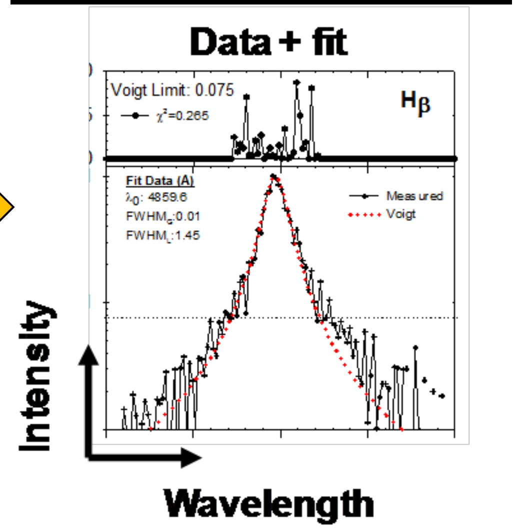
Concept



Scaling trends



Representitive results

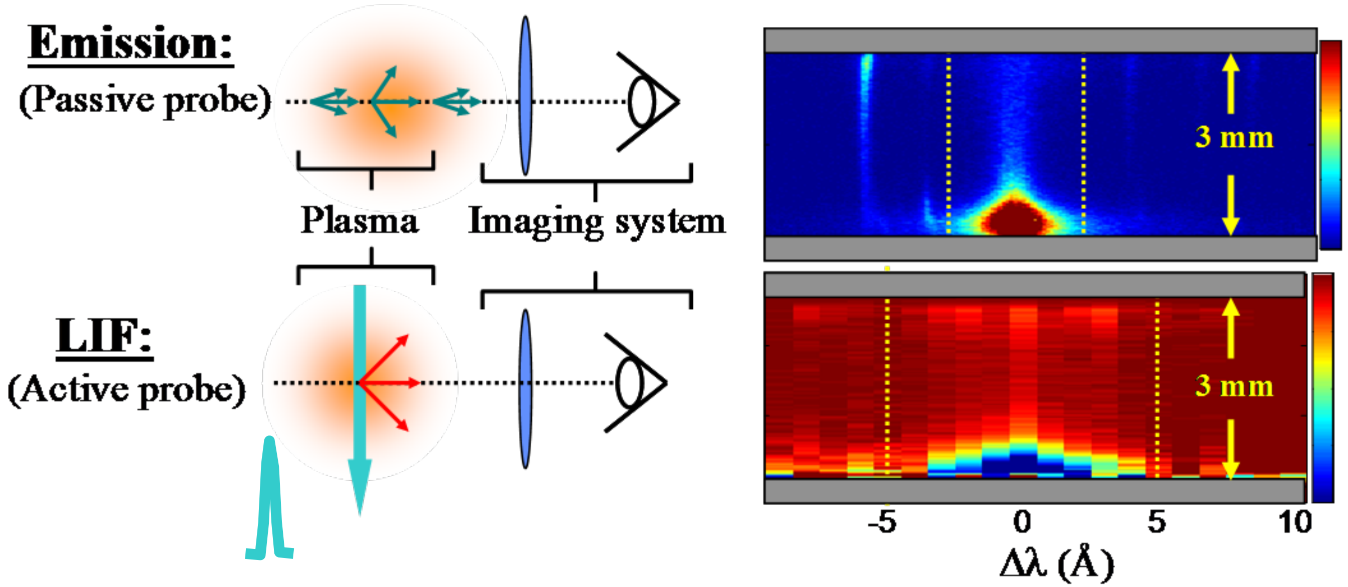


Hydrogen emission is typically used but other species exhibit Stark broadening

Both passive and active interrogation are being considered

- Nanosecond pulsed laser excitation is more difficult, but……
  - Overcomes "line of sight" convolution
  - Better spectral resolution (~ pm) than spectrometers (~10 pm)
  - Can provide 2d spatial maps

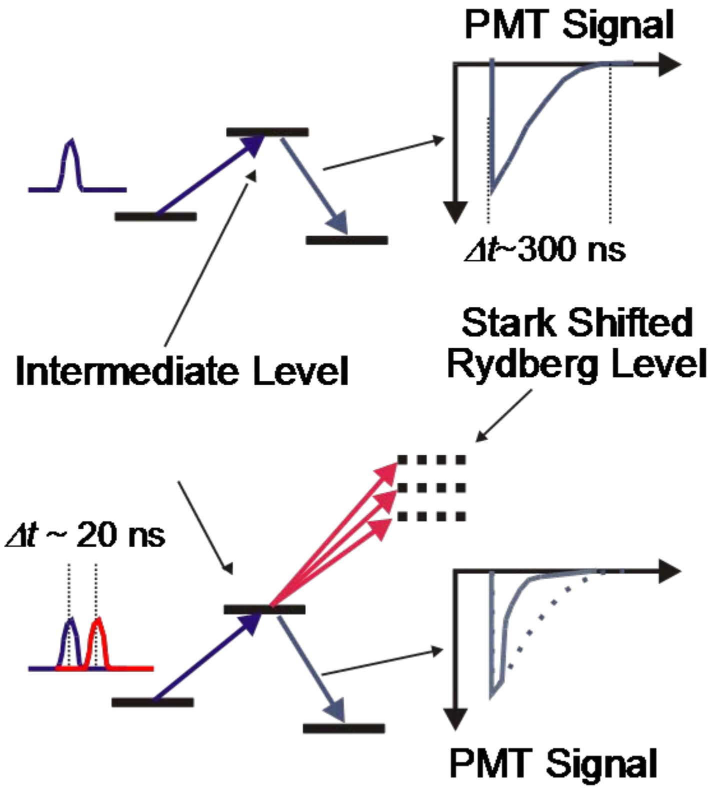
<u>Comparison of the two techniques</u>

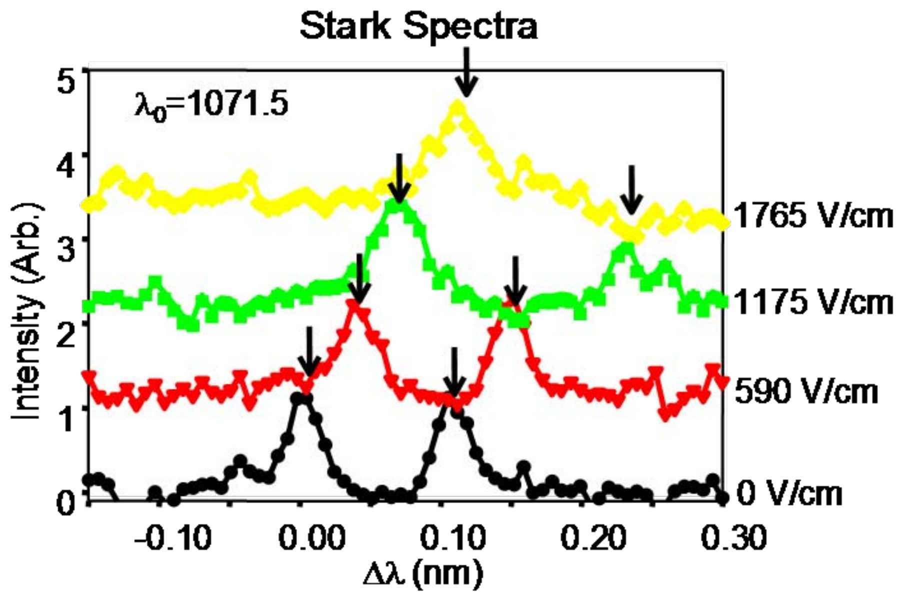


Active interrogation provides more accurate measure of line broadening

LIF-dip technique detects Stark-shifted states of probed atoms

- Fluorescence dip spectroscopy is a two laser technique
  - Probe Stark-shifted Rydberg states
- Transition to the Rydberg level is monitored by a “dip” in the fluorescence from the intermediate state





This technique is not utilized in arc studies but could be…..

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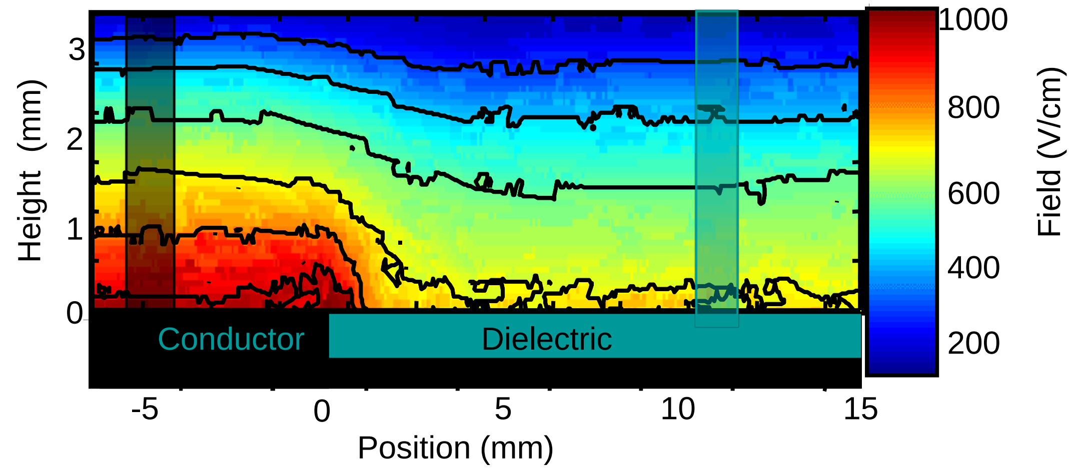
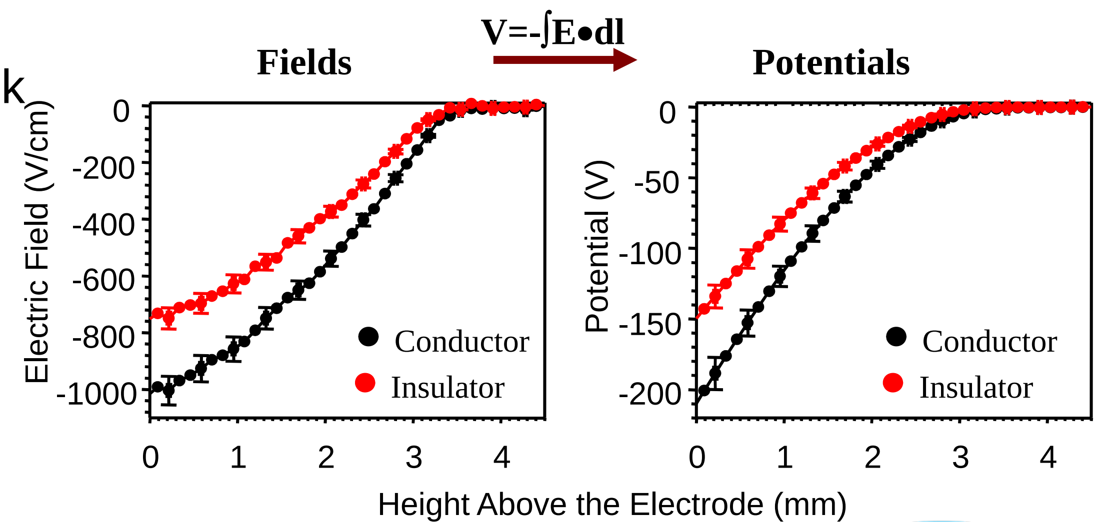
Fields around the interface posses 2-D structure

- Fields are non-uniform across the junction
- Non-uniformity is asymmetric
- Fields are stronger above the conductor
- Both sheaths are ~ 3.5 mm thick
- Potential drop across sheath above dielectric less than that above conductor





400 mTorr Argon; 320 V_{pp} @ 13.56 MHz; 1.5 mm Teflon (κ ~ 2.1)

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Recent validation efforts focus on arc initiation and plasma transportation

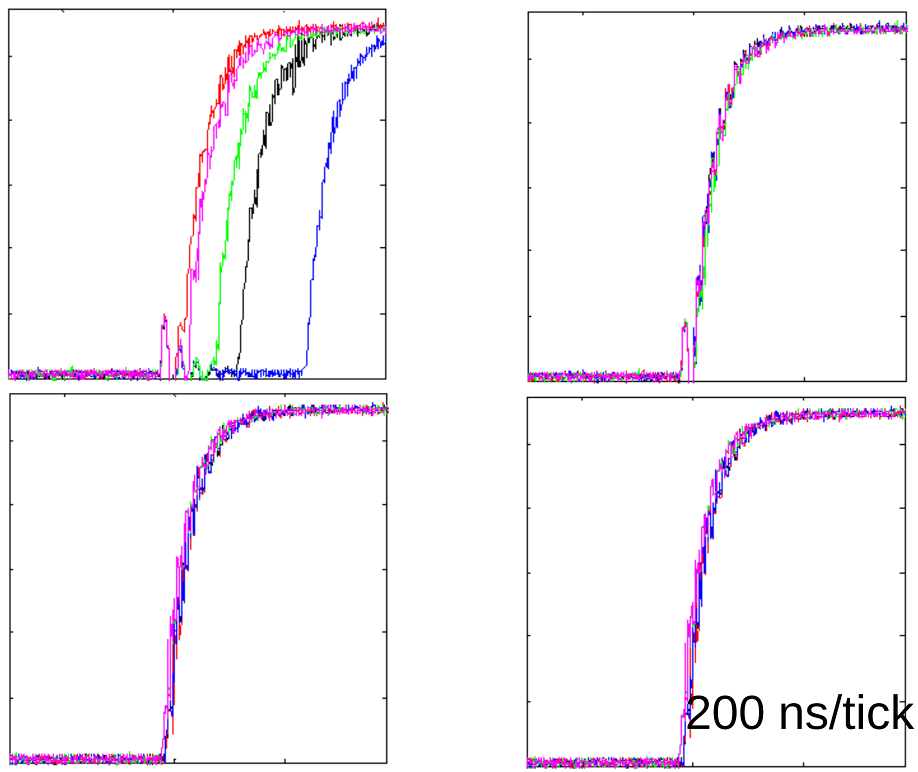
Arc breakdown exhibits stochastic behavior stochastic

- No two arcs are never quite the same
  - This makes studies very difficult
- Clever means are needed to reduce variability

As measured | **Shifted index**

Vacuum

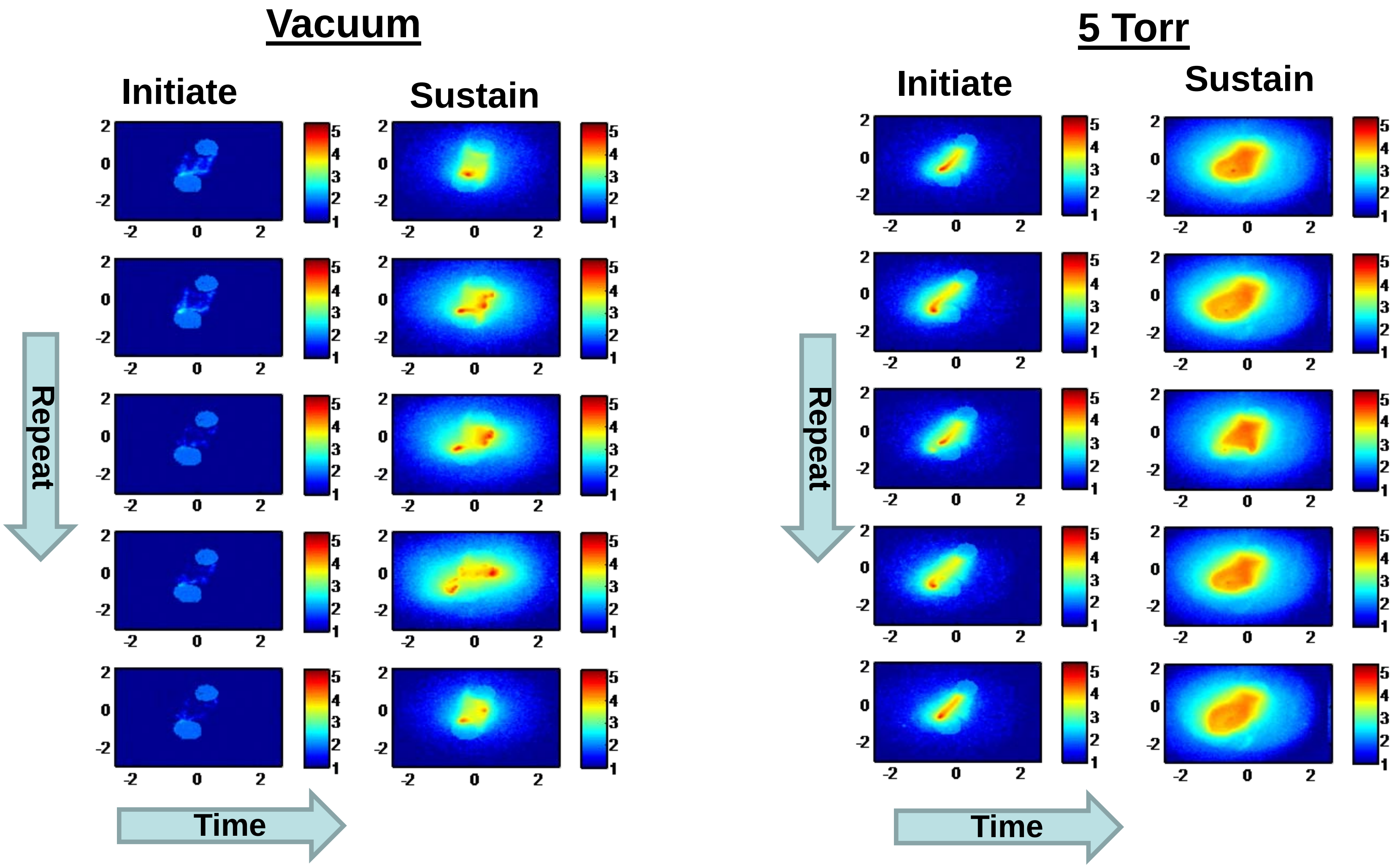
5 Torr



Re-index acquired data to make better sense of observed trends

Comparative 2D imaging of arc breakdown

- The target is to understand vacuum arc physics
  - May need to divide the problem into separate components



Are these two arcs similar enough to make progress…..

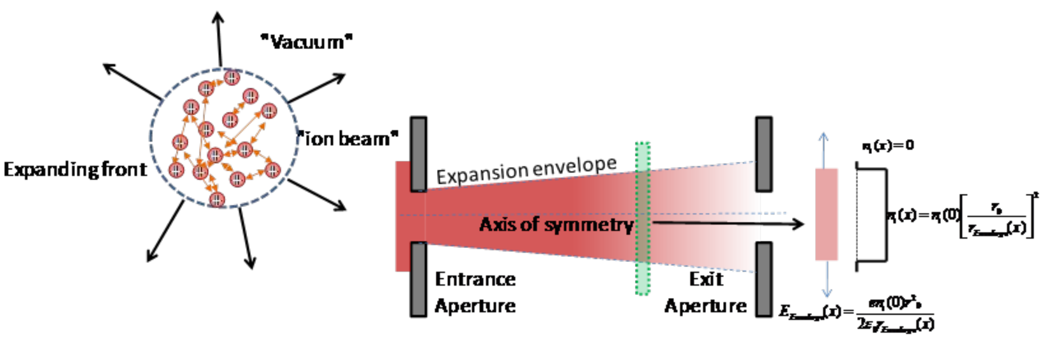
Concluding thoughts and future directions

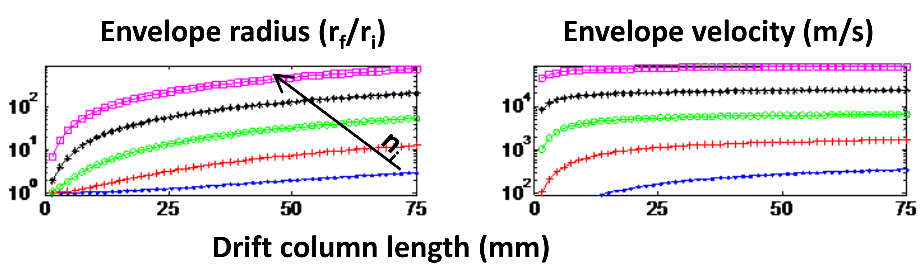
- Emphasis of the talk focuses of techniques that can be utilized to diagnose various aspects of an arc
  - Continuing refinement to improve accuracy of techniques
  - Mindful of other tools that could be brought online
- Validation of code with stochastic sources presents great challenges
  - Look for analogous systems to elucidate key sets of physics

"Sensitivity analysis" gauges performance

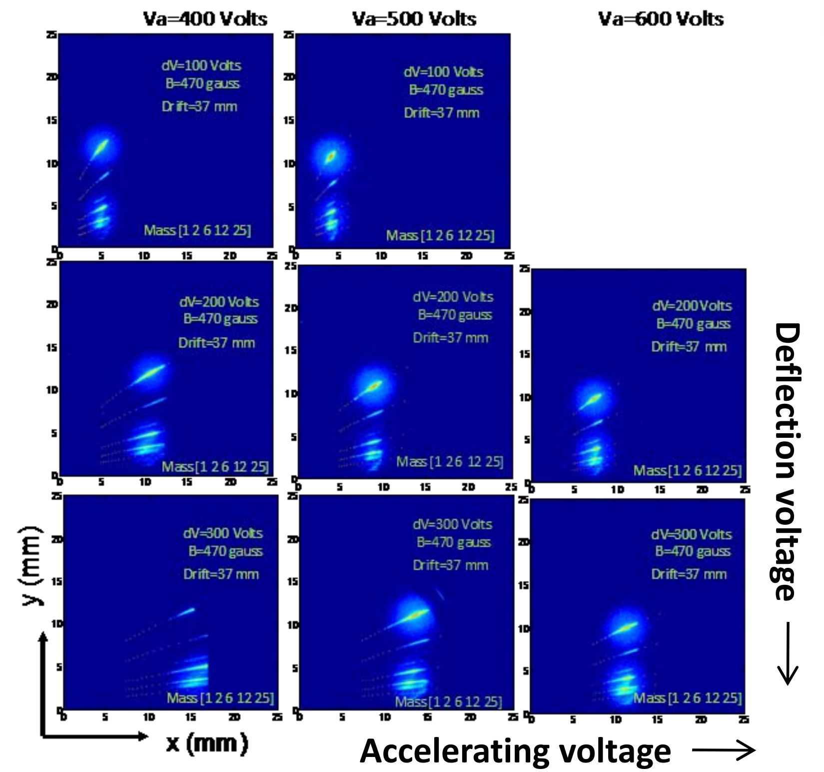
- Need to understand what impacts measurements (energy and mass)
  - Simple models developed and parametric surveys performed
  - Described in SAND report

Space charge induced spreading





Parametric sweep of voltages

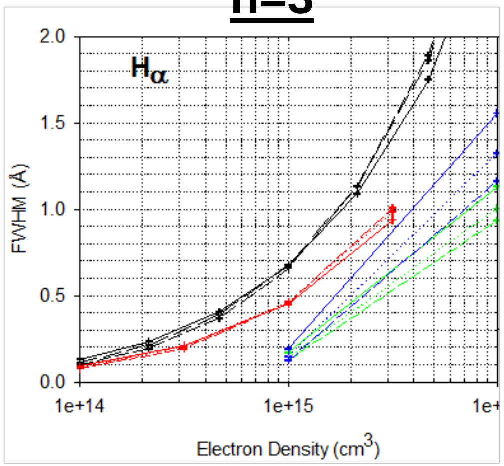


Effort made to place bounds on sources of experimental uncertainties related to design

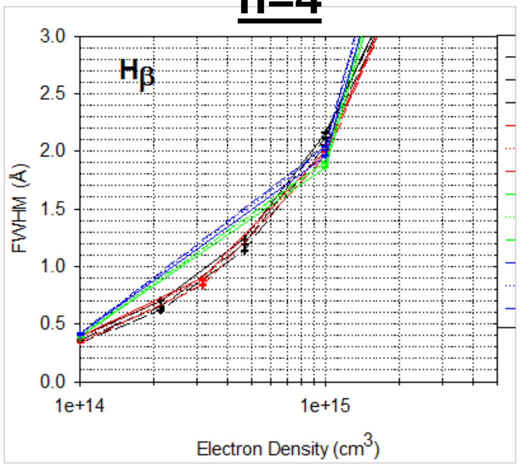
Various models are used to relate broadening to n_e and T_e

- **Several models considered**
  - Time dependant Stark interaction
  - Solve time dependant Schrodinger equation
- **Better agreement between models at higher energy levels**
  - More sensitive to density
  - Less sensitive to electron temperature
- **Limits on density measurements**
  - ~10^{14} electrons/cm^3 via passive emission
  - ~10^{13} electrons/cm^3 via active laser excitation

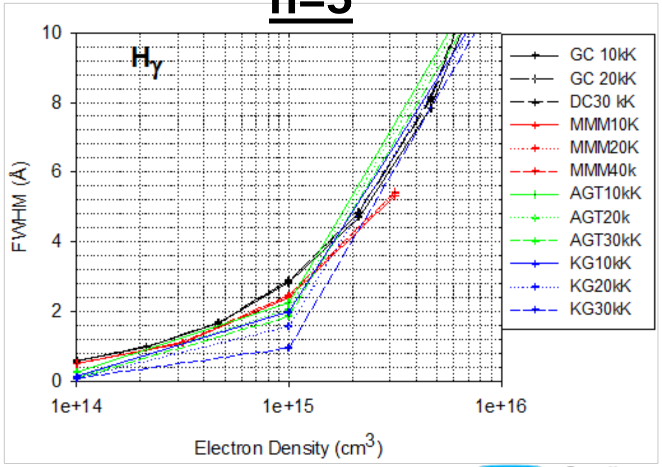
n=3



n=4



n=5



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Aux Slide - Pressure broadening

- **Pressure Broadening**