Two-Dimensional Modeling of a Radically-Convergent Cylindrical Inertial Electrostatic Confinement (IEC) Fusion Device

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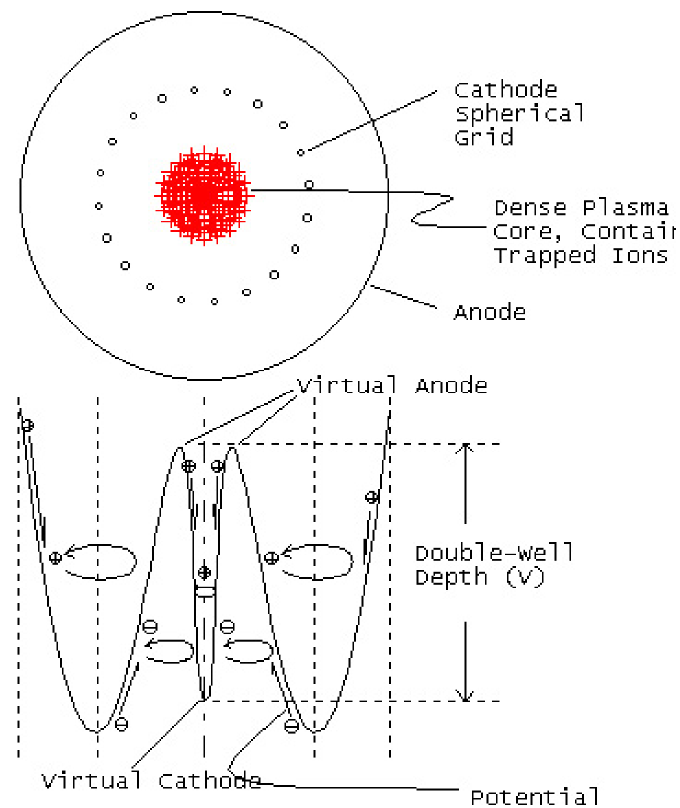
Contents

- Concept of Radially-Convergent IEC
- MCP Model Overview
- Benchmark of MCP Model
- Results
  - Hollow cathode characteristics (qualitative)
  - Star mode light emission source and distribution
  - Space-charge potential scalings.

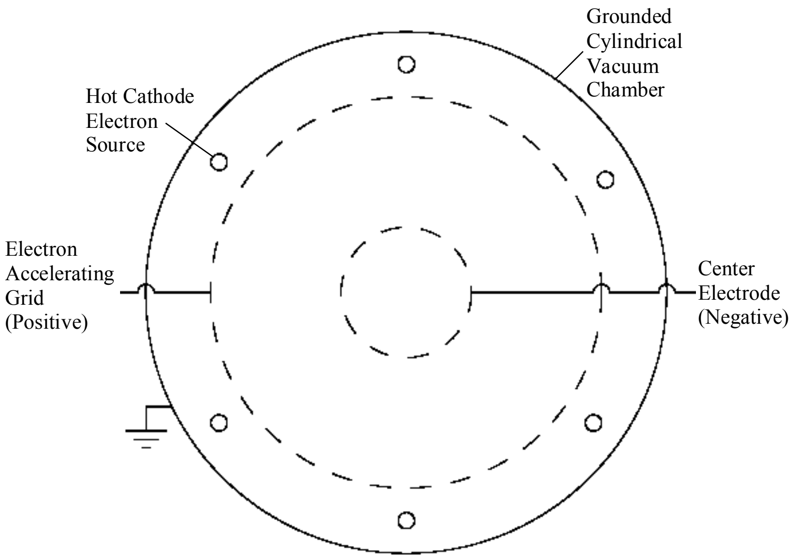
IEC Concept

- High-voltage is applied between spherical transparent grid (cathode) and spherical vacuum chamber (anode).
- Ions accelerate towards the grid, focus in the center, causing a central virtual anode with high ion density
- Electrons focus in the center of the virtual anode creating a virtual cathode.
- Ions confined by virtual cathode fuse with each other.



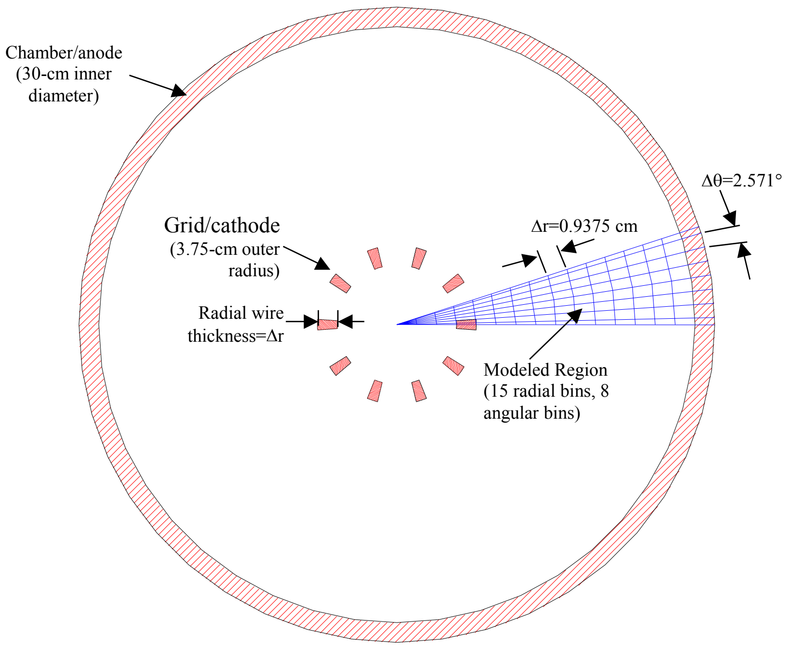
Radically-Convergent Cylindrical IEC (RC-IEC) Device

- Similar to spherical devices, except cylindrical
- Experimental versions used electron emitters and electron-accelerating grid to form ion shell source
- Not tested experimentally in two-electrode discharge mode



RC-IEC Modeled Geometry

- Single cathode grid and cylindrical anode
- Modeled in r-θ coordinates
- Symmetry allows modeling of only a portion of device if discharge is symmetric
- Physics of RC discharge is similar to spherical
- Convenient for modeling because actual physical geometry is well approximated in two dimensions (r,θ)
- Ideal for measurements, but no experimental data available for discharge RC-IEC

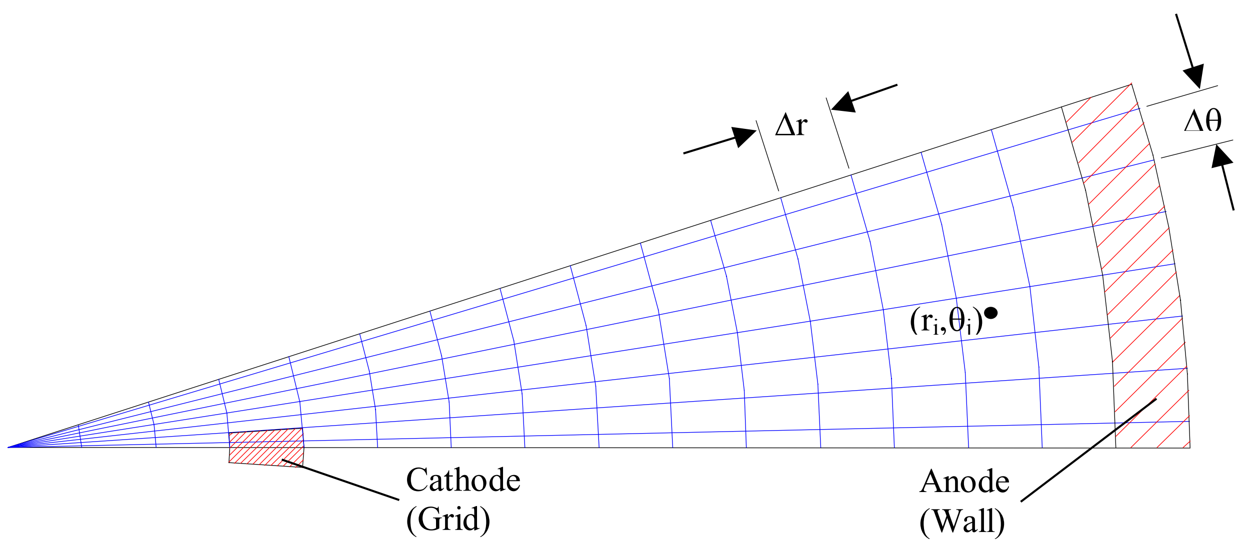


MCP Physics Assumptions

- Steady State
- Gas density >> tracked particle densities (collisions between tracked particles neglected)
- Collisions with large cross sections determine discharge characteristics and performance

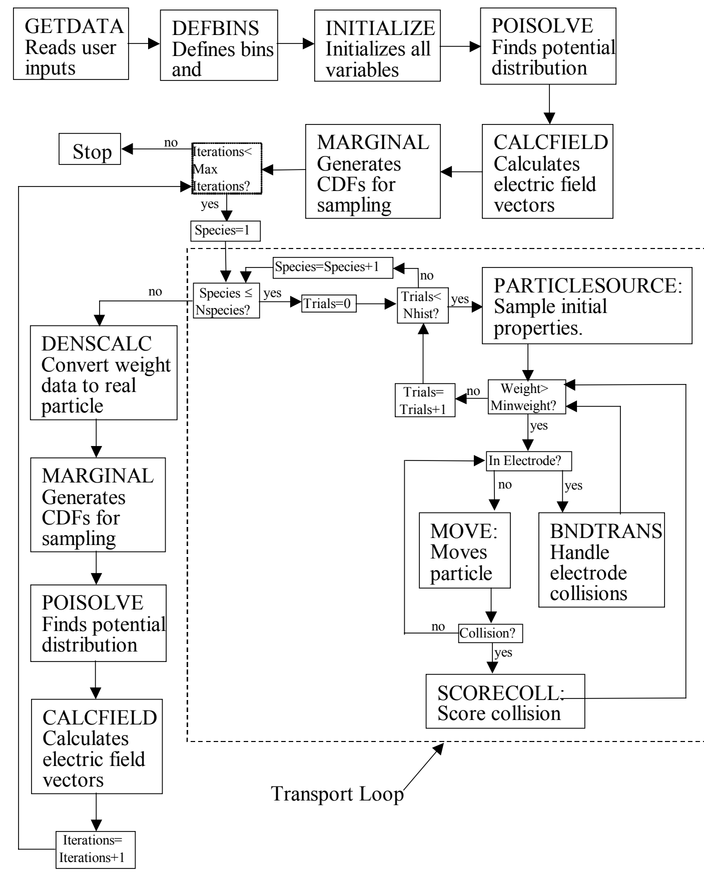
Computational Approximations

- Spatial symmetry on θ-boundaries
- Two spatial dimensions (r,θ)
- Constant electric field within a bin
- Particle sources are uniform over a bin (position, energy, or direction)



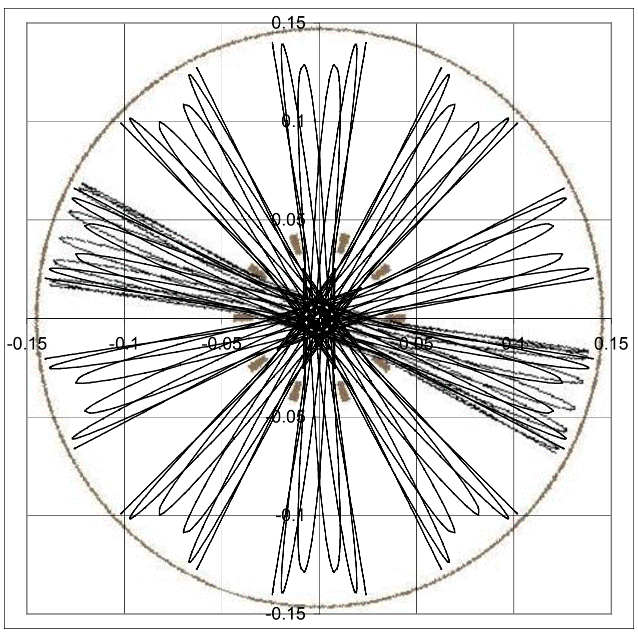
MCP Algorithm

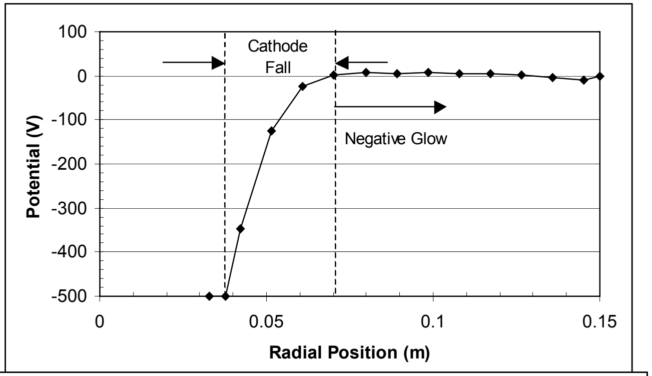
- Initialization
- Transport: particle moving, gas collisions and electrode collisions
- Calculate real particle data and space-charge dependent potentials
- Iterate (transport-potential)
- No particles created or destroyed
  - weights adjusted
  - Particle Number is conserved

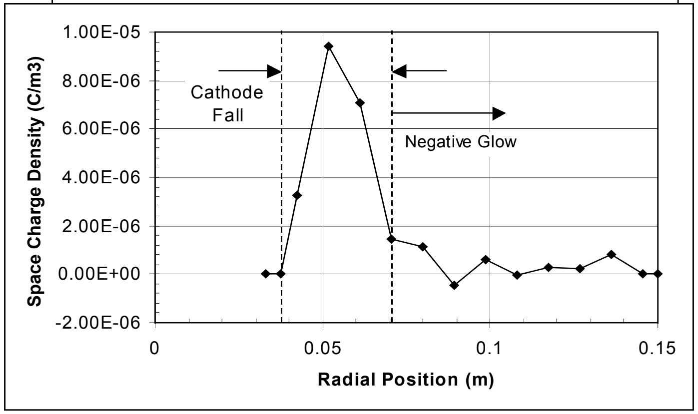


Benchmarking MCP

- For low-pressure
  - Verified by SIMION code
- For high-pressure
  - Benchmarked by Glow-discharge





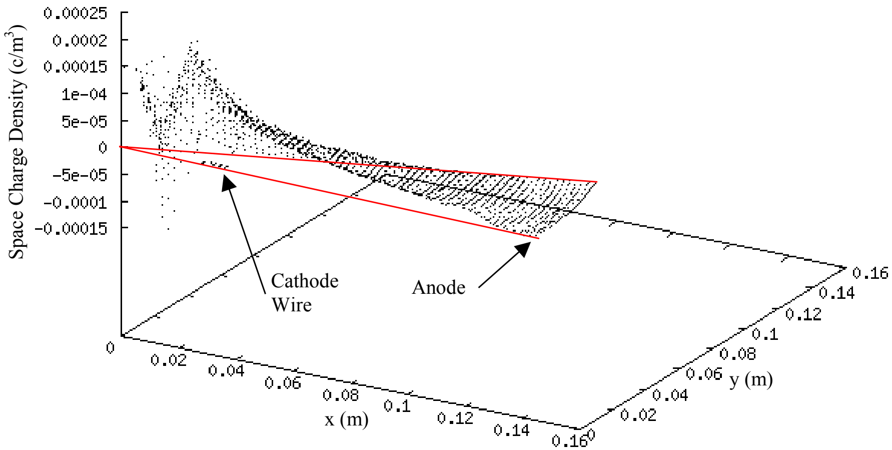


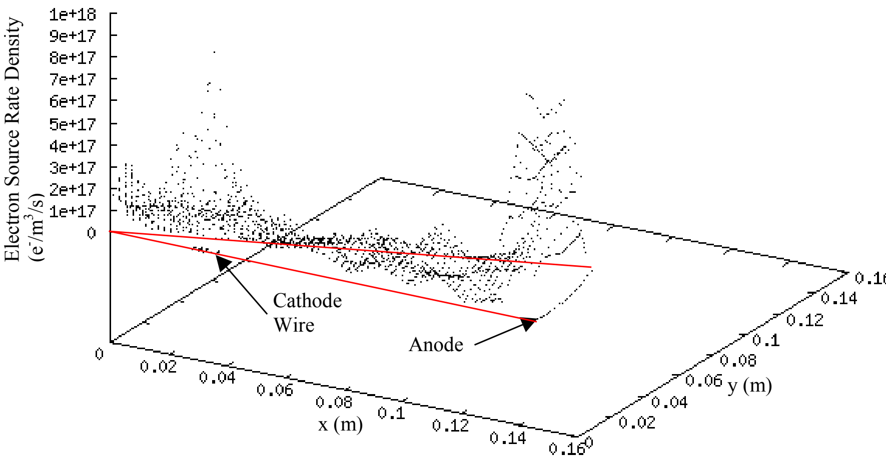
Results Overview

- Hollow cathode characteristics (qualitative)
- Star mode light emission source and distribution
- Space-charge potential scalings

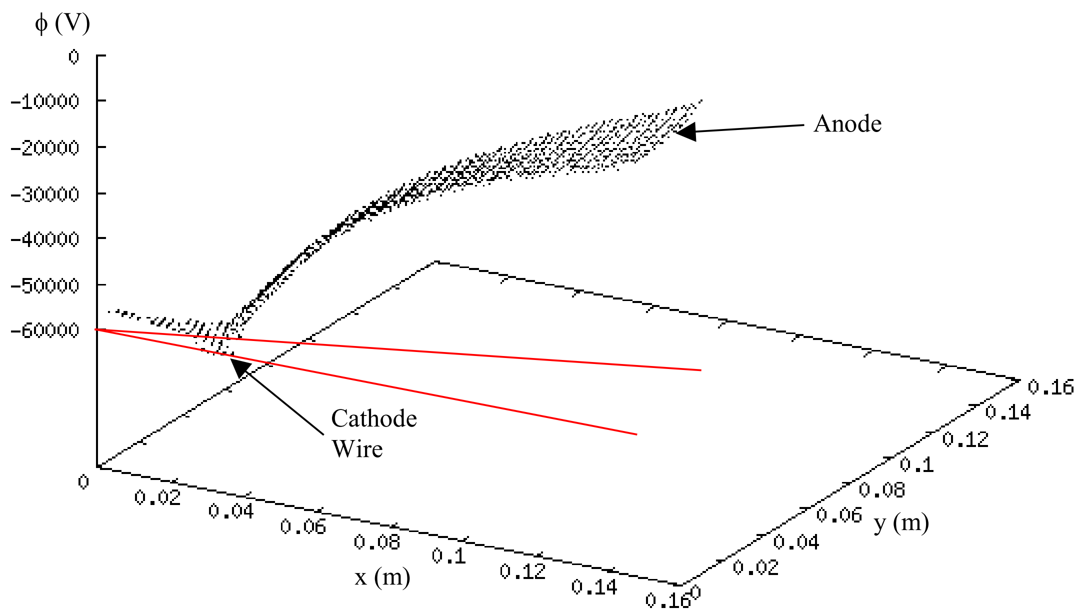
Hollow Cathode Characteristics

- Positive space charge density peaks in center, causing a virtual anode
- Central virtual anode allows electron recirculation
- Recirculating electrons cause high ionization rate density in center



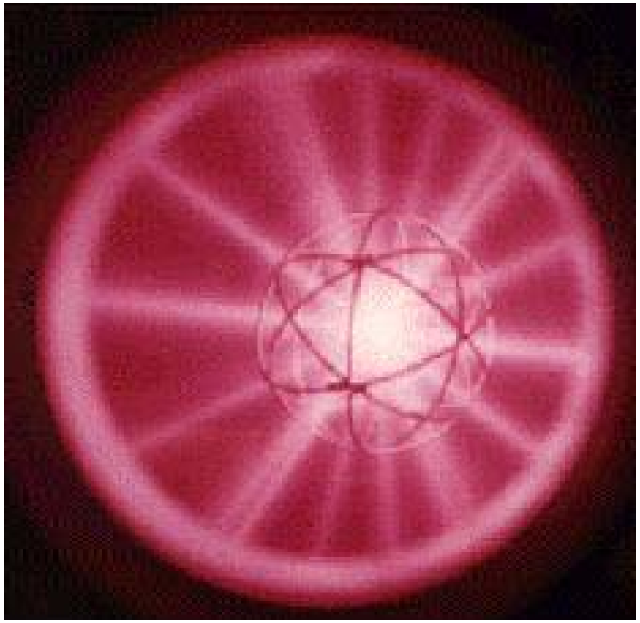


- Potential distribution within RC-IEC



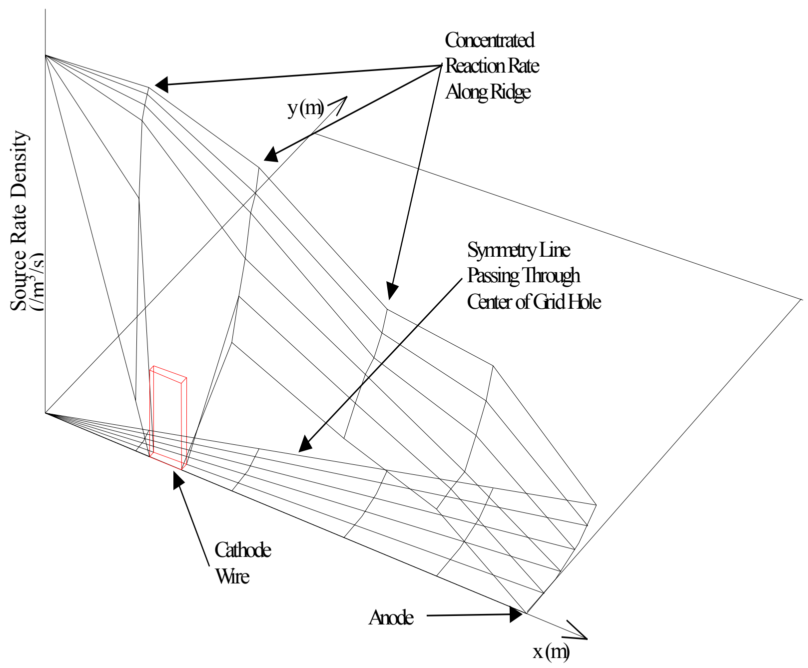
Star-Mode Light Emission

- Light intensity peaks along center line of spokes, fades as anode approached
- Source of light emission was thought to be electron-impact excitation



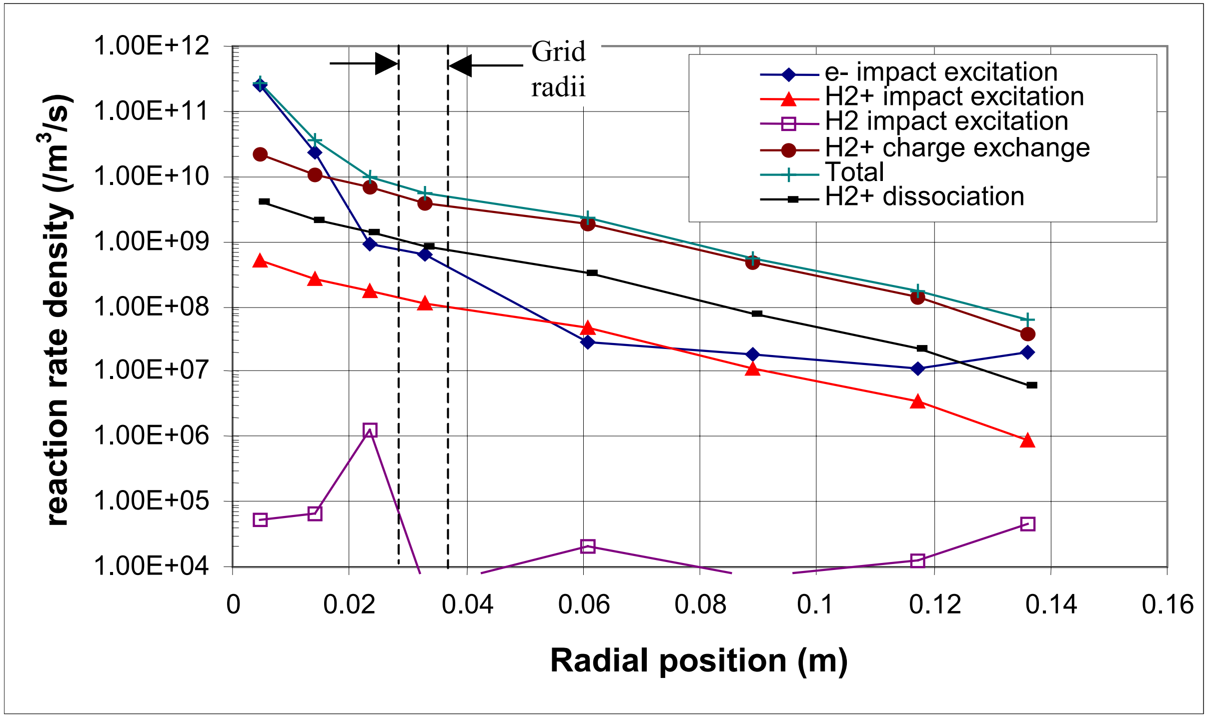
MCP's Star-Mode Results

- Light producing reactions:
  - Charge exchange
  - Impact excitation
  - Molecular-ion dissociation
- Source rate density should be concentrated along spoke centerline (symmetry line)



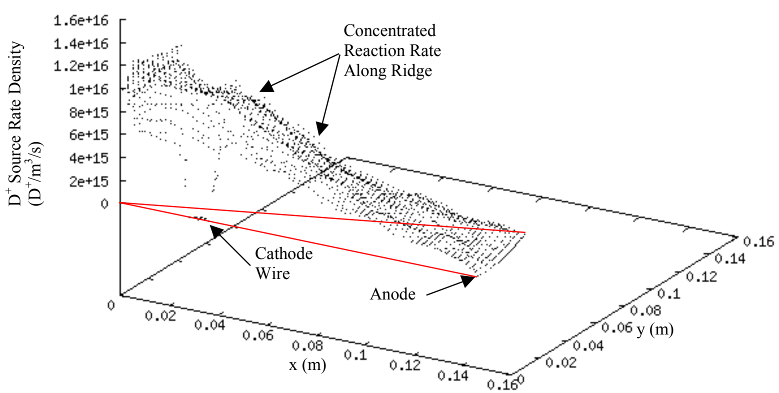
Reaction Rate Densities

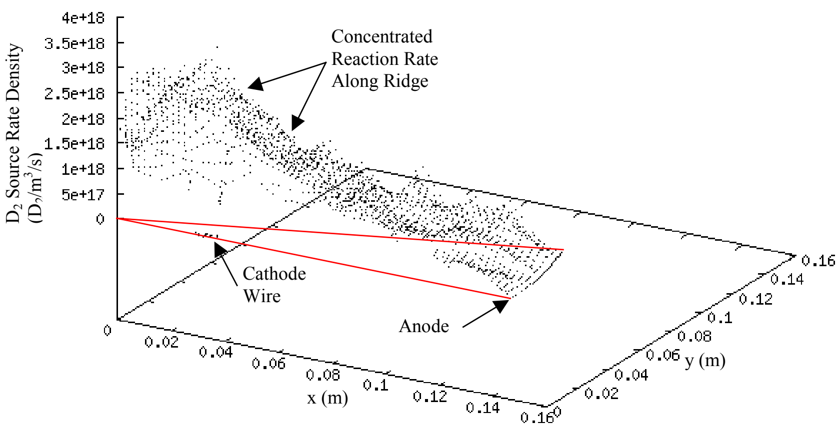
- Calculated reaction rate density for light-producing reactions along symmetry line
- Molecular-ion charge exchange and dissociation produce most light in spokes
- Electron impact excitation produces light in core



Rate Density Distributions

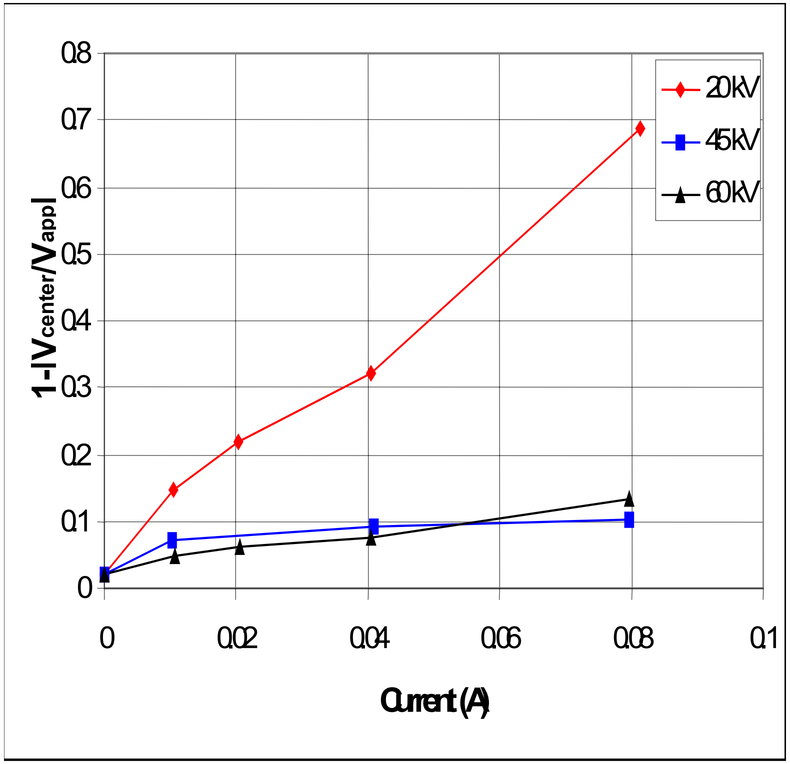
- Molecular-ion charge exchange produces fast D_2
- Molecular-ion dissociation produces D^+ and D
- Source rate density distributions are peaked along symmetry line





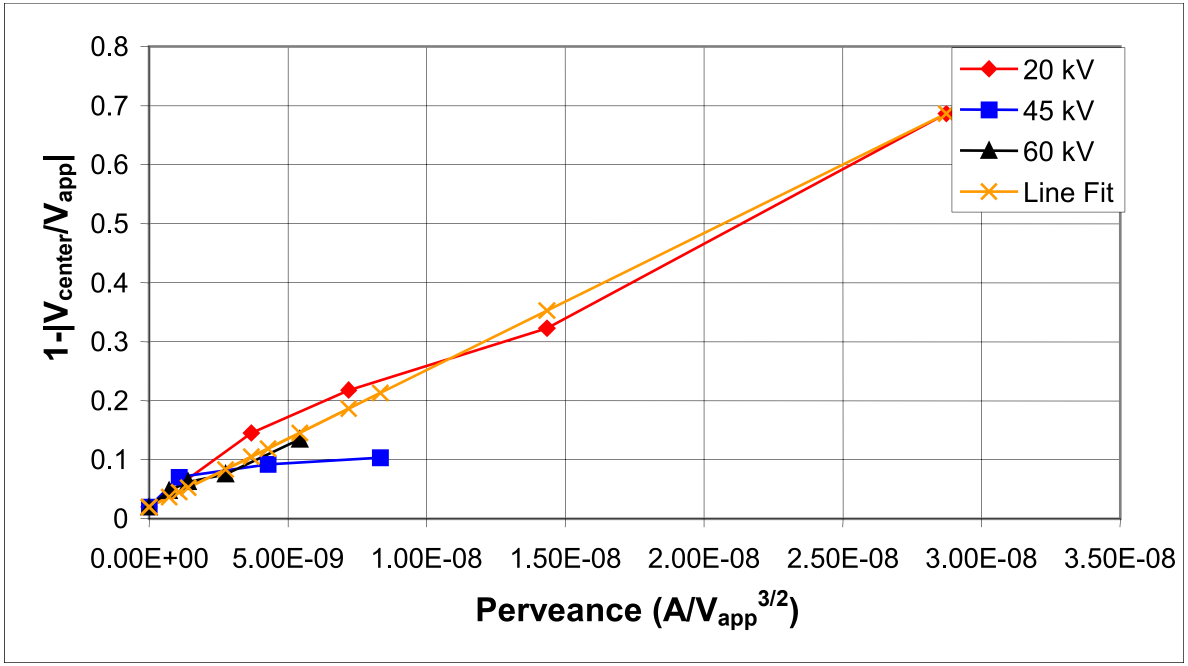
Virtual Anode vs Current

- Central virtual anode height increases with increasing current
- 45-kV and 60-kV cases are separate from 20-kV case
- Try fit with perveance ($I/V^{3/2}$)



Virtual Anode vs Perveance

- Perveance: natural parameter choice
- Virtual anode height seems to scale linearly at low voltages
- Possible secondary electron effects at higher voltages



Summary and Conclusion

- Star-mode light emission
  - Light emission in spokes is dominantly from charge-exchange molecular fast neutrals
  - Light emission in core region is from electron-impact excitation of background gas
  - Concentration of charge exchange collisions and dissociation collisions along grid-hole symmetry line coincides with spoke-like appearance of Star-mode light
- Potential distributions
  - Central virtual anode causes a hollow-cathode discharge with high ionization rate density in center
  - Virtual anode height increases with increasing current
  - Linear relation between virtual anode height and perveance seems to exist, but must be verified

Thank You.

- Acknowledgment:

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