Effects of detailed charge exchange interactions in DSMC-PIC simulation of a simplified plasma test cell

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MOTIVATION & METHODOLOGY

Key Motivation: Desire to evaluate heavy-species collision models in a plasma environment which is much simpler than a Hall effect thruster.

Specific Goal: Refine heavy-species interactions for kinetic methods.

Methodology: Use kinetic, particle-in-cell (PIC) tool, MONACO-PIC (MPIC) to study elastic and inelastic heavy-species processes.

-- Perform numerical counterpart to representative experiment @ UCLA

-- Upgrade and refine new differential cross-section and post-collision scattering models.

-- Compare results and analyze disparities

NUMERICAL APPROACH

DSMC-PIC method for non-equilibrium plasma:

-- Developed since the 1960's.

-- Charged particles move in physical space.

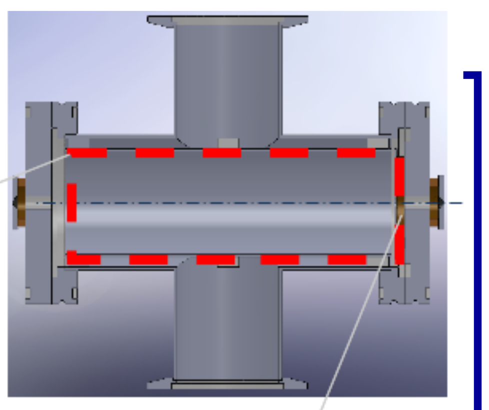
-- Particles possess molecular properties, e.g. u' (thermal velocity).

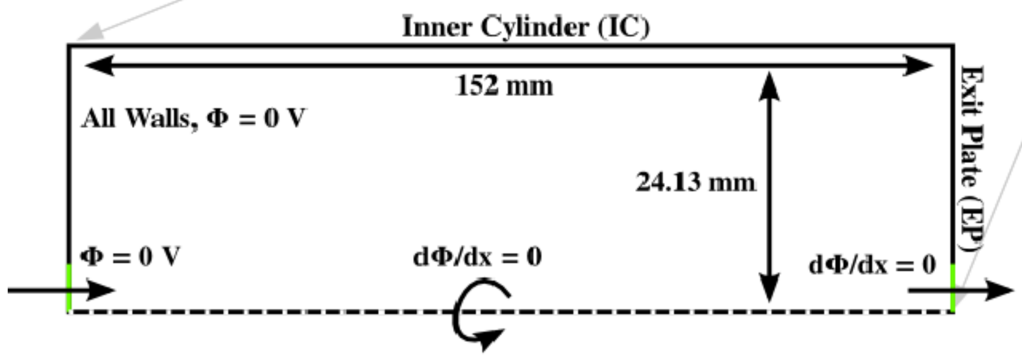
-- Cell size $dx \sim \delta$, time step $dt \sim 1/\omega$.

-- Self-consistent electric fields, E.

-- Collisions handled statistically.

-- Charge (CEX) and momentum (MEX) exchange.





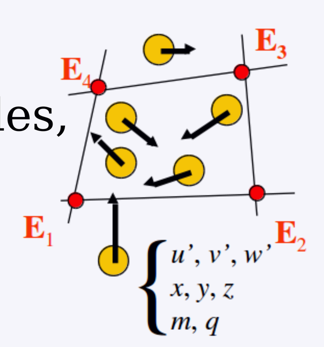
Our tool: **MONACO-PIC (MPIC)**

-- 2d cylindrical,

-- Parallelized,

-- Ions & neutrals → particles,

-- Electrons → Boltzmann.



Our domain: **the "test cell" by *Wirz, et al*[4]. @ UCLA**:

-- Axi-symmetric domain.

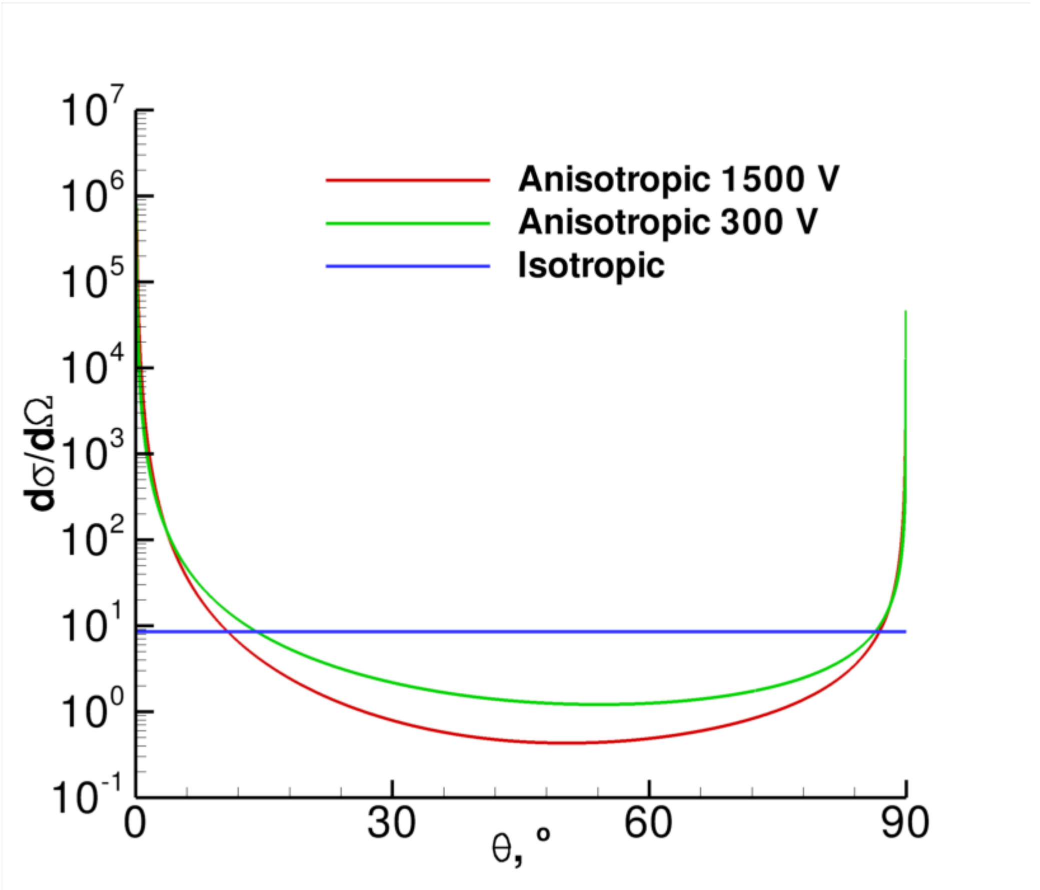
-- Held at specific background pressures.

-- Injection beam of 1500 eV xenon ions.

-- Two regions of interest: **Inner Cylinder (IC)** and **Exit Plate (EP)**

General Numerical Parameters: 700,000 to 8,000,000 particles, 1×10^{-8} s timestep, corresponding to an injection beam velocity of 47,000 m/s @ 29 nA.

EVOLUTION OF SCATTERING MODELS



Isotropic: Uses total cross-sections of *Miller, et al.*[1], in which a post-collision scattering angle is assigned randomly via a unit-sphere.

Total cross-section: $\sigma_{CEX} = 171.23 - 27.2 \log(g)$ Ang^2

$\sigma_{MEX} = \sigma_{CEX}$

Anisotropic (300 V): Uses differential cross-section fit of *Scharfe, et al.*[2], which is fit to a 300 V interaction, an energy most relevant to Hall effect

Curve-fit: $d\sigma/d\Omega = \theta^{Ael}10^{Bel} + (90-\theta)^{Act}10^{Bct}$

Fitting Parameter	Value
A_{el}	-2.02
B_{el}	3.24
A_{ct}	-1.098
B_{ct}	1.53

Anisotropic (1500 V): Uses methodology of Dressler, *et al*[3]., to calculate a refined curve-fit for the Scharfe curve, resulting in less "intensity" at intermediate angles.

Total cross-section always conserved.

Fitting Parameter	Value	Value, refined
A_{el}	-2.02	-2.502
B_{el}	3.24	3.508
A_{ct}	-1.098	-1.38
B_{ct}	1.53	1.61

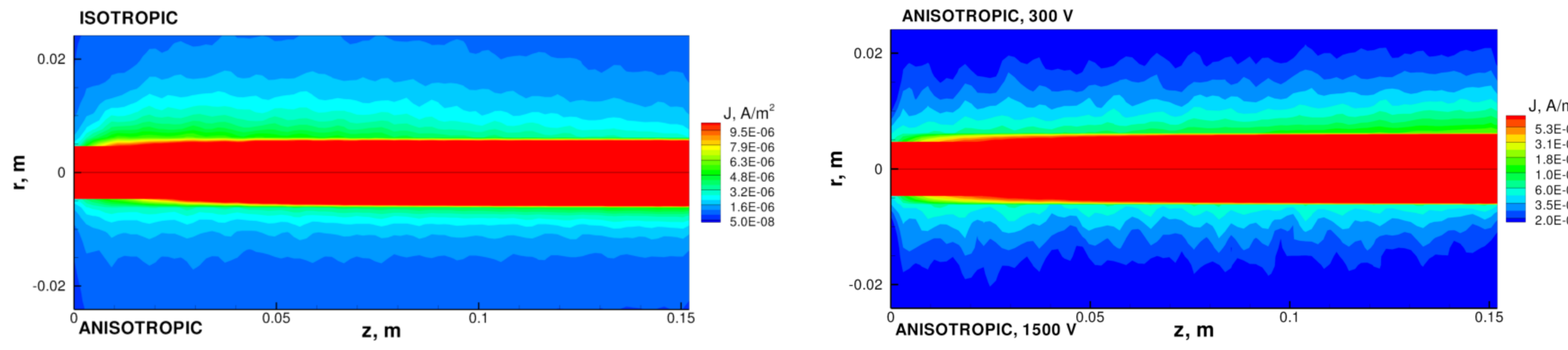
[1] J. S. Miller, S. H. Pullins, D. J. Levandier, Y. Chiu, and R. A. Dressler. Xenon charge exchange cross sections for electrostatic thruster models. Journal of Applied Physics, 91(3):984–991, 2002.

[2] M. K. Scharfe, J. W. Koo, and G. M. Azarnia. DSMC Implementation of Experimentally-Based Xe++ Xe Differential Cross Sections for Electric Propulsion Modeling. In 27th International Symposium on Rarefied Gas Dynamics, number 10271

[3] R. A. Dressler, Y. Chiu, D. J. Levandier, C. Houchins, and C. Y. Ng. Large-Angle Xenon Ion Scattering in Xe-Propelled Electrostatic Thrusters: Differential Cross Sections. Journal of Physics D: Applied Physics, 41(16):165503, August 2008.

[4] R. Wirz, L. Chu, M. Patino, H. Mao, and S. Araki. Well-Characterized Plasma Experiments for Validation of Computational Models. In 32nd International Electric Propulsion Conference, pages IEPC–2011–122, Wiesbaden, Germany, 2011.

CURRENT DENSITY RESULTS



Isotropic vs. Anisotropic (300 V):

-- Scattering behaviour fundamentally different.

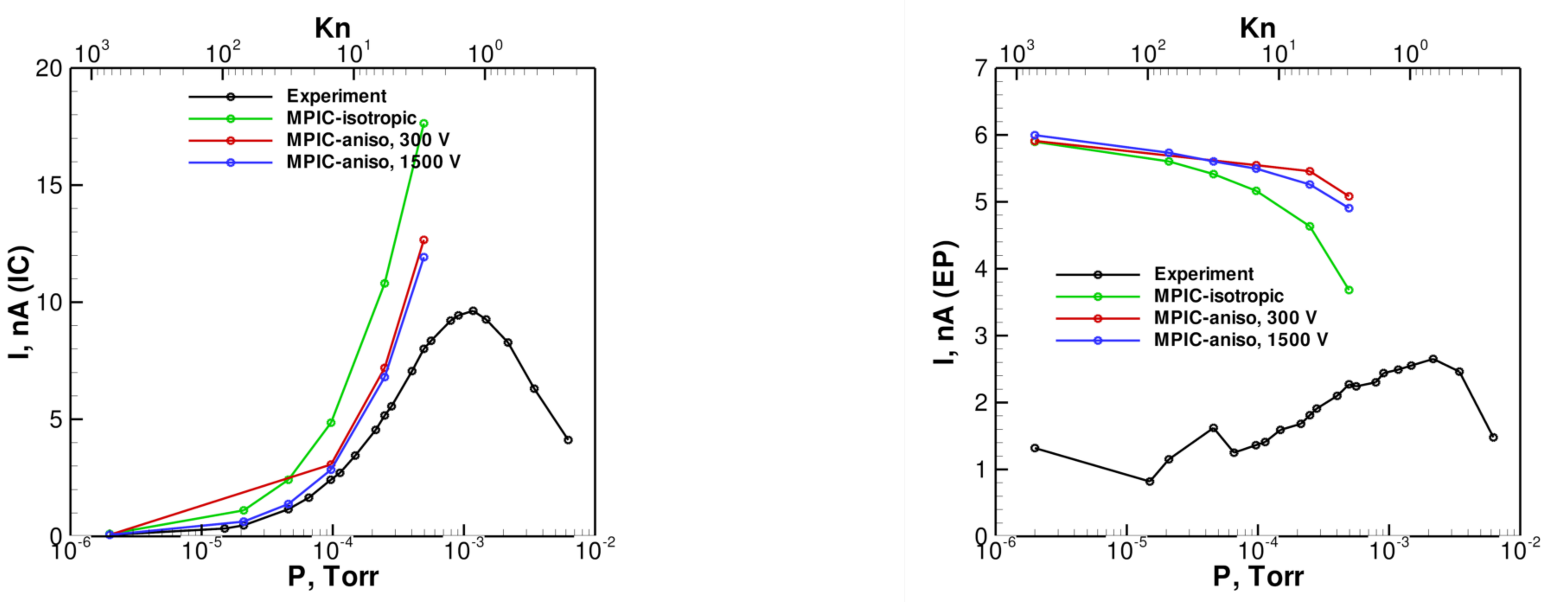
-- New model leads to less intermediate angle scattering (predicted)

Anisotropic (300 V) vs. Anisotropic (1500 V):

-- Scattering behaviour changes slightly

-- Refined model leads to even less intermediaite angle effects.

ELECTRODE CURRENT COMPARISONS

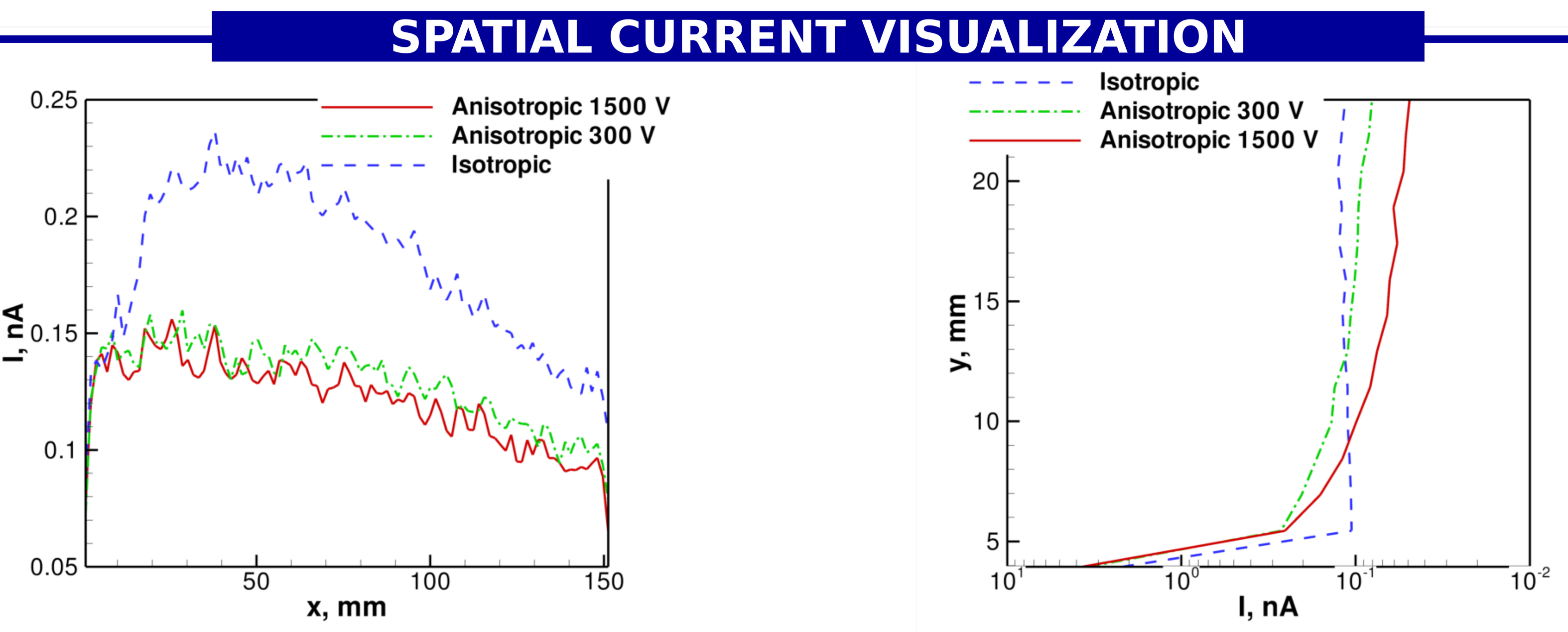


Refined anisotropic model brings IC current collection closer to experiment.

-- Less intermediate scattering events leads to less current collected.

-- Exit plate (EP) trends do not follow experiment and require further investiagtion.

SPATIAL CURRENT VISUALIZATION



Spatial distribution of current is important for future experimental design:

-- Can visualize decrease in intermediate scattering angles.

-- Future experimental comparisons possible due to segmented electrode design.

SUMMARY & FUTURE

Successfully increased fidelity of heavy species interaction models in MONACO-PIC

-- Refined, anisotropic model fits best with experimental comparison.

-- Future experimental methods will allow spatial current collection somparison.

-- There is a need for more physics: SEE current adjustment, metastable species, etc.

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