Modeling Plasma Interactions with Satellite-Borne Instrumentation

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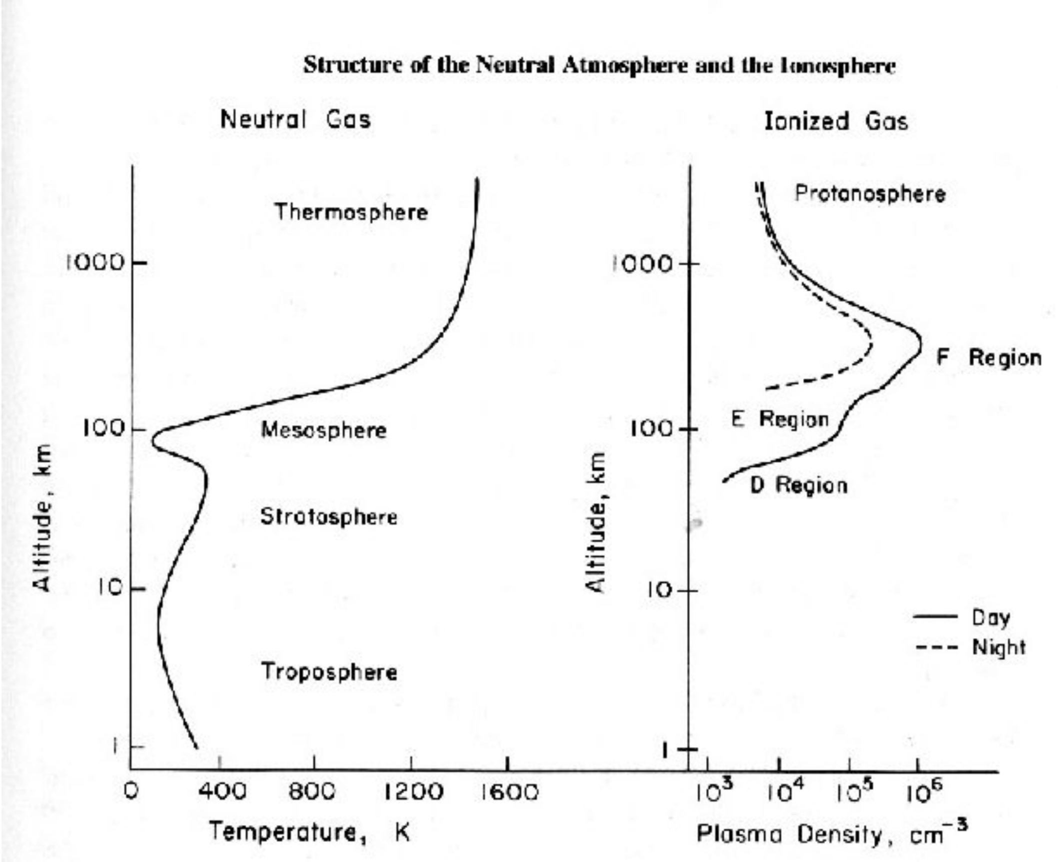
Outline

- How do instruments measure thermal charged particle distributions?
- How are the data analyzed?
- Can the effects of non-ideal grids be simulated?
- What are the errors associated with existing analysis techniques?

Atmospheric Plasma

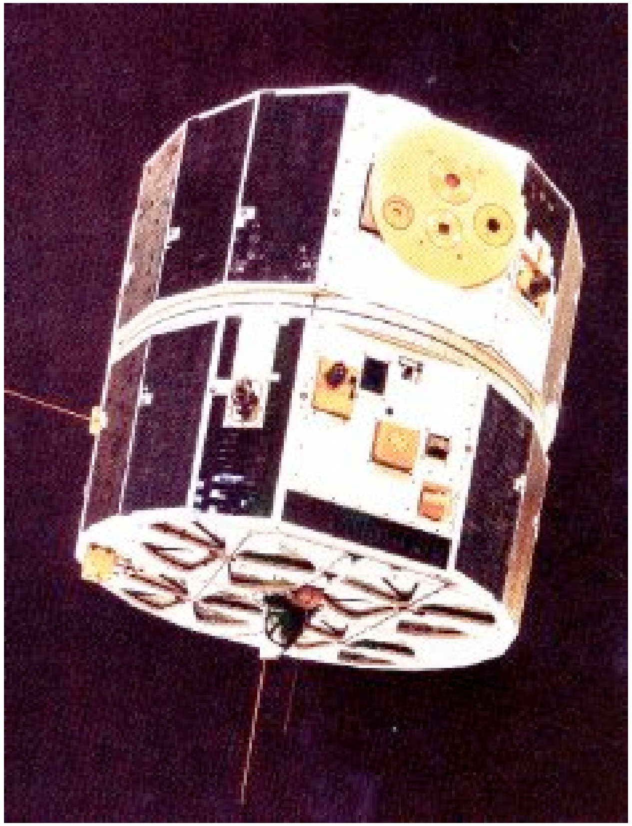
- Ionosphere
  - 50-2000km
- Neutral gas ionized by solar radiation



www.utdallas.edu/research/spacesciences/ionosphere.htm

Satellite Measurements

- High-velocity satellite motion approximates plasma beam behavior
- Plasma characteristics
  - Velocity
    - Ram (in-track)
    - Cross-track
  - Density
  - Temperature



Retarding Potential Analyzer

- DMSP
- Viking Lander
- Sputnik III
- C/NOFS

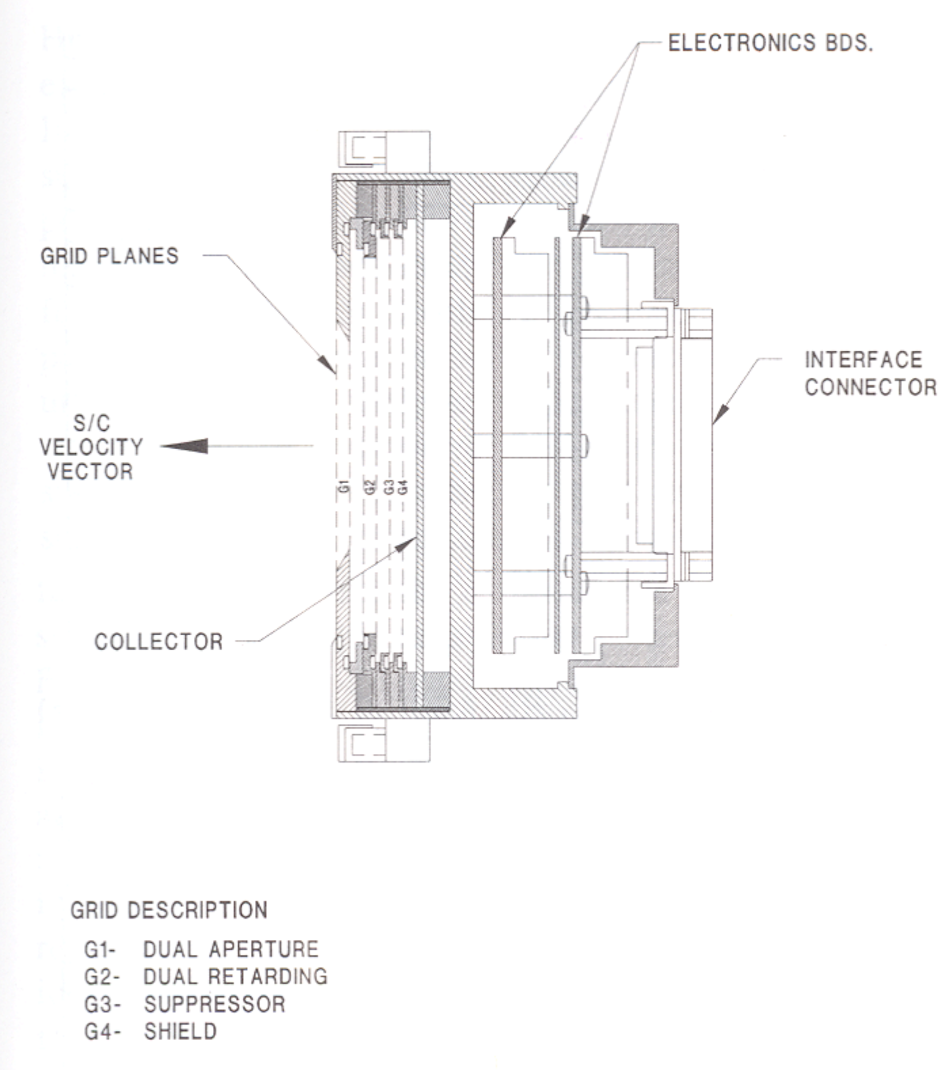
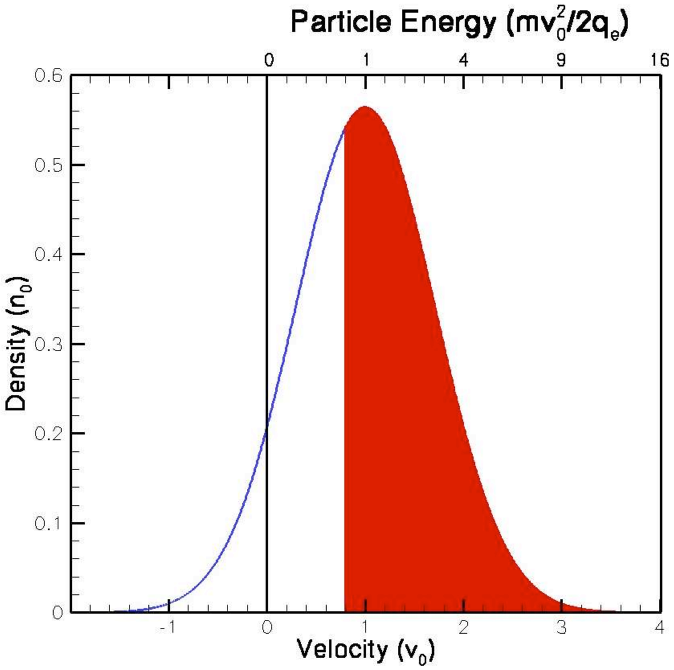
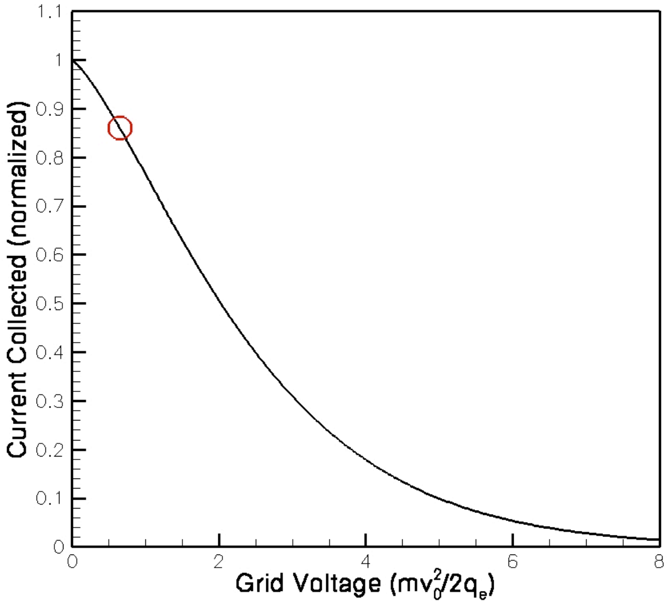


Diagram from Heelis/Hanson, Geophysical Monograph 102, AGU

Retarding Potential Analysis

- Uses an “Energy Filter” to select a portion of the incoming distribution
  - Gold-coated tungsten wire woven into a mesh
  - Soon to be replaced with flat, laser-etched grids





The Analytic Solution

- Integrate ion flux over velocities that penetrate the filter

$$I(V) = \int_{v_{j-stop}}^{\infty} q_e A v \mathcal{D}_{1D}(v) dv$$

- Assume distribution is Maxwellian

$$I(V) = q_e A \sum_j \frac{n_j v_{j0}}{2} \left[1 + erf(\kappa_j) + \frac{\exp(-\kappa_j^2)}{\sqrt{\pi} v / \alpha_j} \right]$$

$$\kappa_j = \left(v_{j0} - v_{j-stop} \right) / \alpha_j$$

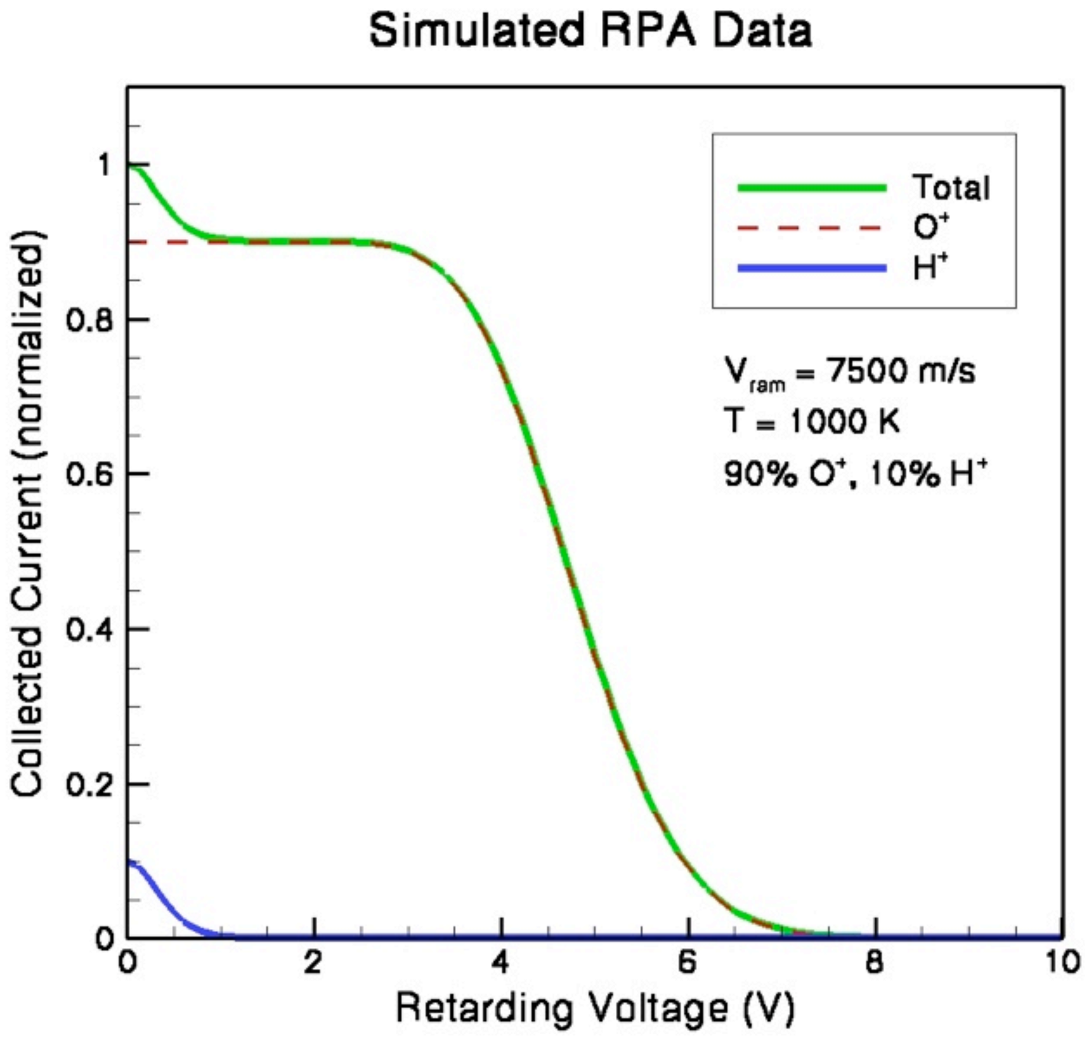
- This form is often used in a Levenberg-Marquardt fitting routine

Multiple Species

The currents are simply additive.

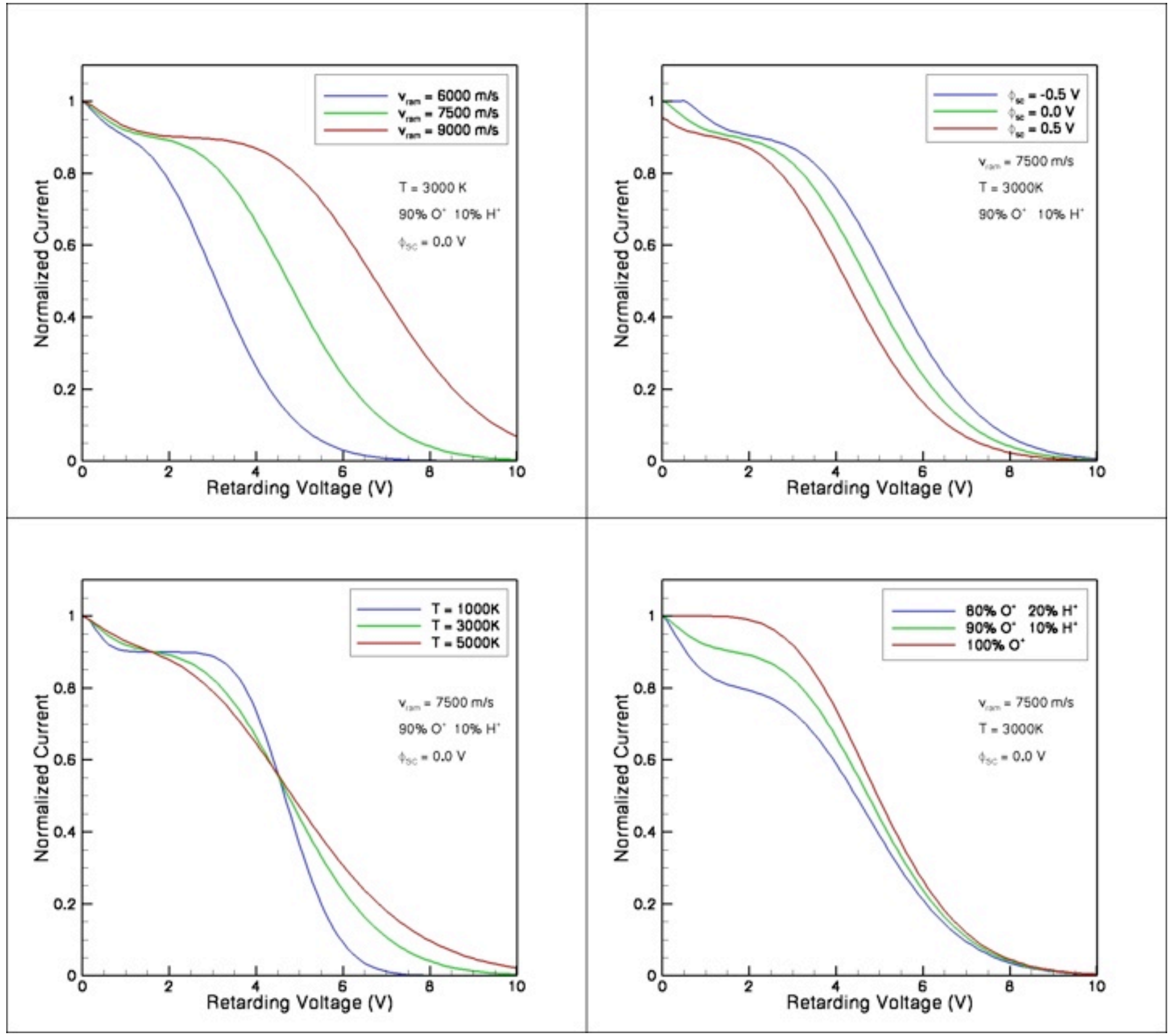
Drift velocity identical for multiple species.

Species mass determines stopping energy.



Parameter Interpolation

- 4 parameters to fit
  - Velocity
  - Spacecraft Potential
  - Temperature
  - Composition
- Interdependent trade-offs between fit values
  - Velocity and Potential
  - High Temperatures



Problems with the Ideal Assumptions

- Non-uniform potential in the RV grid plane
- Angular dependencies for transmission
- Grid thickness
- *Space charge effects*
- *Grid surface contaminants*

The General Solution

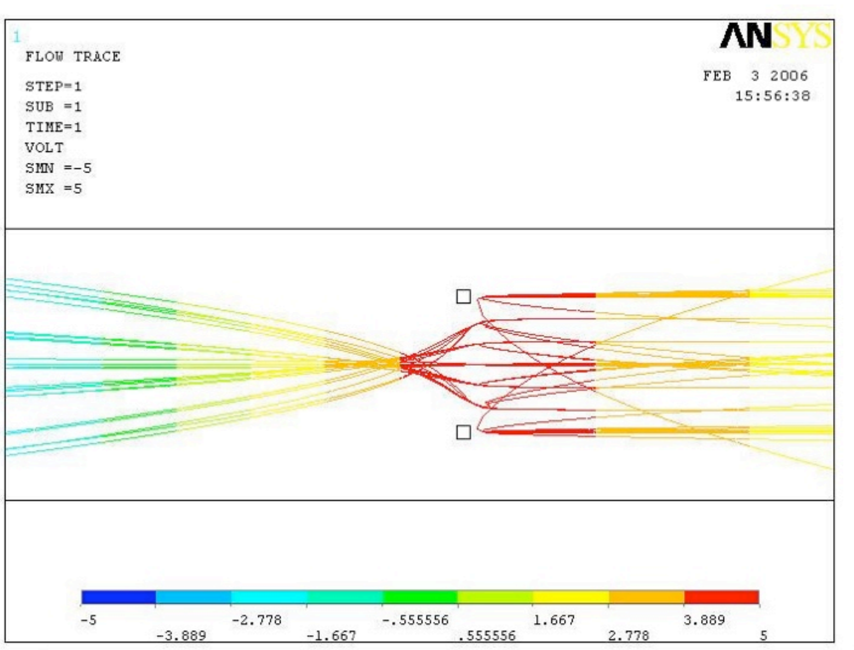
- The flux integral is modified by a transmission function (chi)

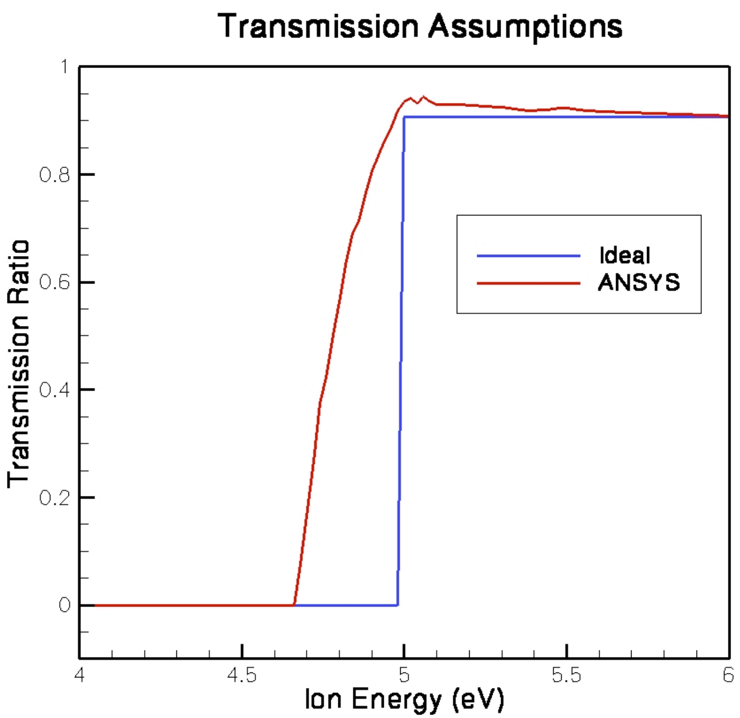
$$I = q_0 A \int_{v_x, v_y} \int_{v_z=0}^{\infty} \chi(\vec{\mathbf{v}}) v_z \mathcal{D}(\vec{\mathbf{v}}) d\vec{\mathbf{v}}$$

- This function cannot be determined analytically without making large sacrifices in model accuracy

Statistical Simulation

- The ANSYS® Academic Research Product
  - Electric field calculations
  - Particle tracing routines



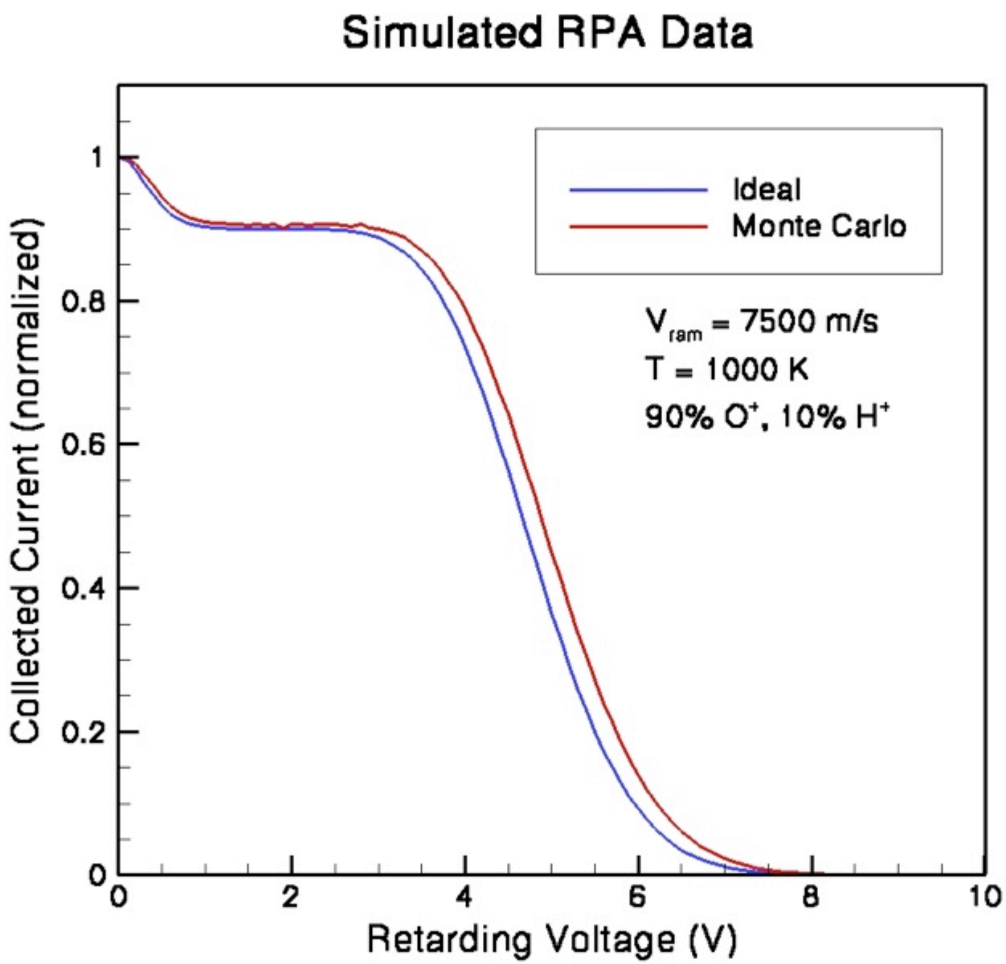


Monte Carlo Simulation

- We can calculate the IV curves using a Monte Carlo routine for integration.

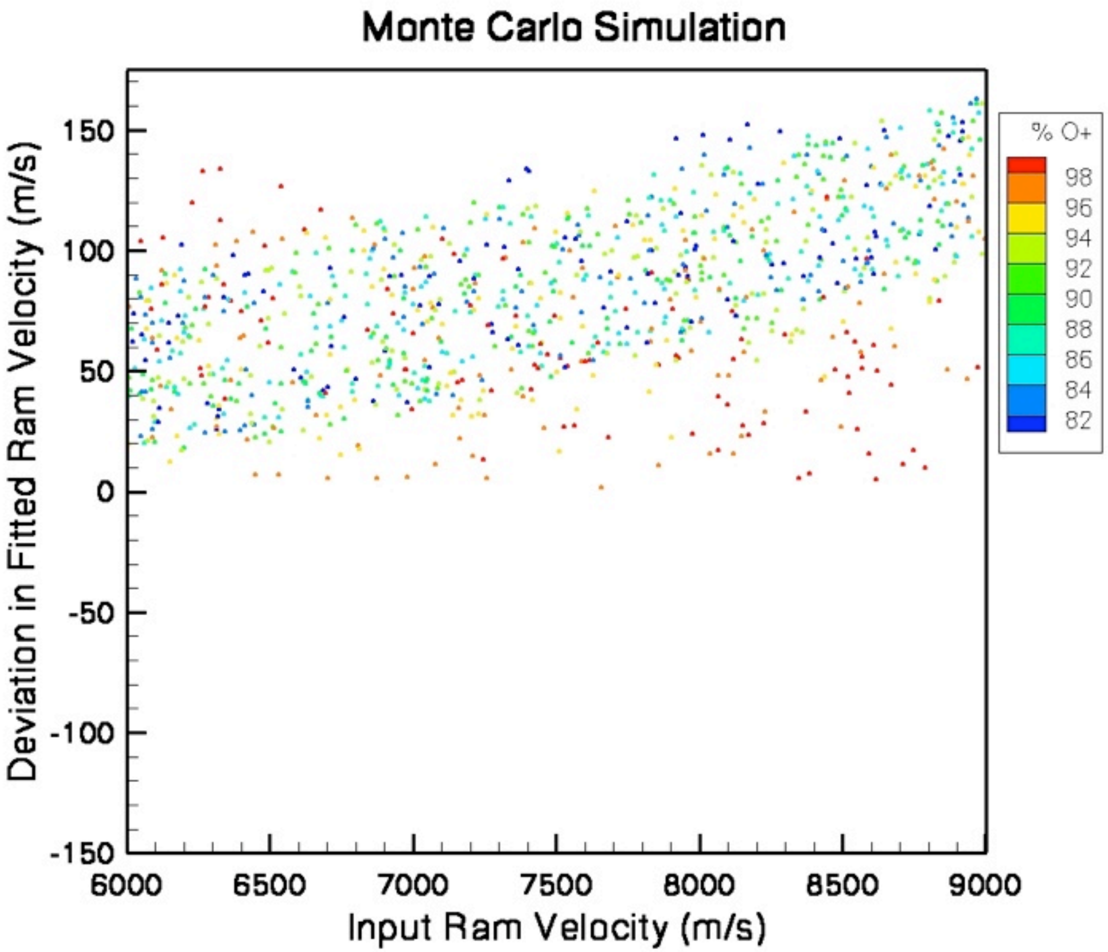
$$I_i = \frac{V_{\vec{\mathbf{v}}}}{N} \sum_{a=1}^{N} \chi_{i-a} v_{z-a} \mathcal{D}(\vec{\mathbf{v}}_a)$$

- Results for the single-grid case show excess current over all voltages.



Single-Grid Results

	Mean	σ
Δv_{ram}	$81\ m/s$	$35\ m/s$
ΔT	$102K$	$43K$
Δf_{O+}	1.4%	0.8%
$\Delta \phi_{sc}$	$-0.1V$	$0.04V$



Full analysis being prepared for publication

Future Work

- Full simulation of double-grid case
  - RWS in progress
  - DMSP RPA?
- Characterize errors associated with current instruments
- Modify analysis routine