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Ion Species Measurements in the Source Region of the UW-IEC Device

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Ion Species Measurements Motivated by Computational Work

- Computational work done by Emmert and Santarius shows atomic physics effects to dominate the behavior of IEC devices operating at high neutral gas pressures.

Ionization of D_2:	$e + D_2 \rightarrow D_2^+ + 2e$	Dissociative ionization of D_2:	$e + D_2 \rightarrow D^+ + D + 2e$
Dissociation of D_2:	$e + D_2 \rightarrow 2D + e$	Dissociative recombination of D_2^+:	$e + D_2^+ \rightarrow 2D$
Ionization of D:	$e + D \rightarrow D^+ + 2e$	Interchange reactions creating D_3^+:	$D_2 + D_2^+ \rightarrow D_3^+ + D$
Dissociation of D_2^+:	$e + D_2^+ \rightarrow D^+ + D + e$	Dissociative recombination of D_3^+:	$e + D_3^+ \rightarrow D_2 + D$

- A 0-D rate equation calculation based on ion source conditions, done by G.A. Emmert, shows high concentrations of molecular ions.

Calculated Source Mixture:

85% D_3^+, 12% D_2^+, and 3% D^+

At 2 mtorr neutral gas pressure

Ion Species Measurements Motivated by Computational Work Cont.

- High concentrations of molecular ions are predicted to have a significant effect on the fusion rate

Fusion Rate	unit	**Single-Species Code (US/Japan 2005)**	**Multiple-Species Code (US/Japan 2007)**
Predicted neutron rate (model)	s^{-1}	**0.96×10^8**	**1.7×10^8**
Measured neutron rate (166kV, 68mA, 10cm cathode)	s^{-1}	**1.8×10^8**	

Experimental Verification of Molecular Ions in the Source Region is Desired

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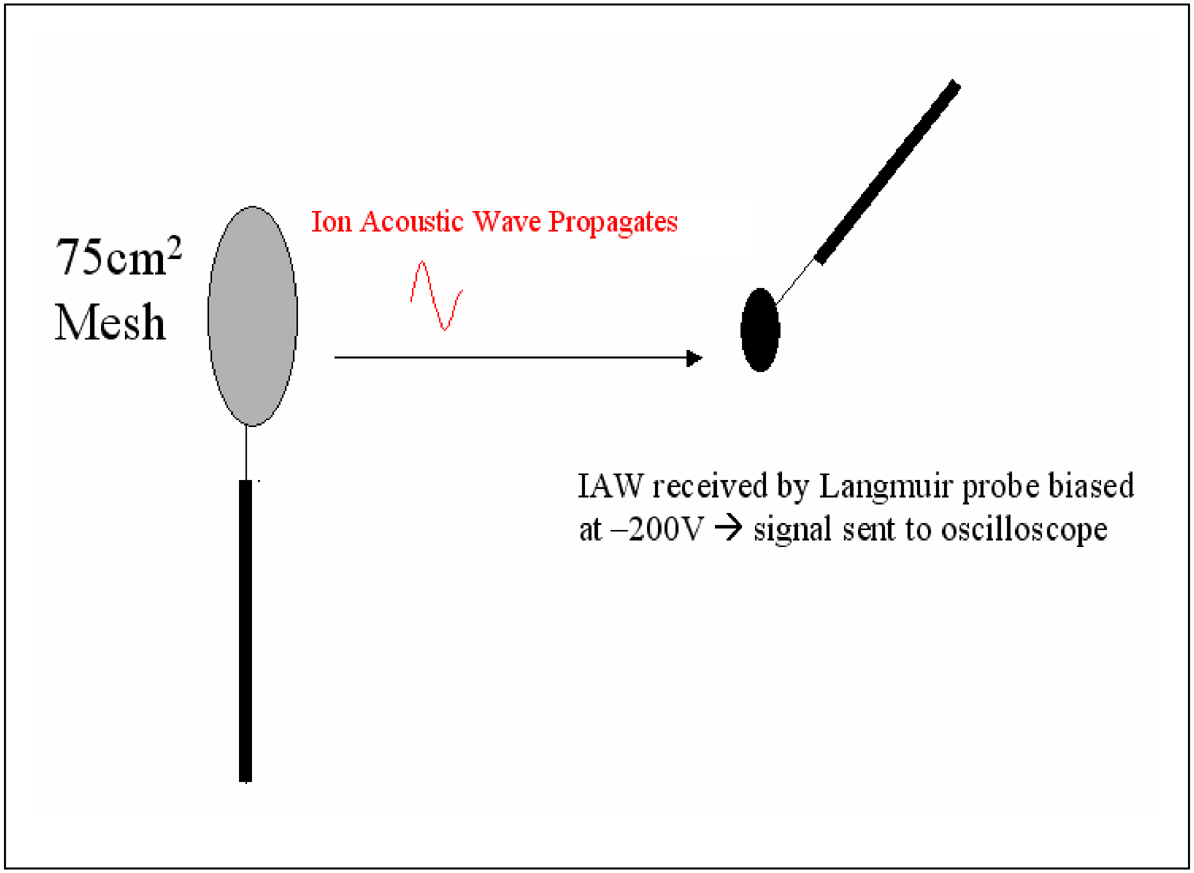

- Ion Acoustic Wave (IAW) velocities can determine ion mass
- IAW phase velocities (v_{ph})depend on M, ion mass, and T_e, electron temperature.
- By measuring v_{ph} and T_e the ion mass can be calculated.

Ion Acoustic Wave Method for Determining Ion Mass Ratios

- Ion Acoustic Waves are electrostatic plasma waves that have a mass dependent phase velocity. Where $v_{ph}=\omega/k$
- The two species Ion Acoustic Wave Dispersion Relation shown below:

$$\frac{\omega}{k}=\sqrt{c_{s1}^2+c_{s2}^2} \quad \text{where} \quad c_{sj}=\sqrt{\frac{n_j kT_e}{n_e M_j}}$$

- c_{sj} is the sound speed of the jth ion species.
- M_j is the ion mass of the jth ion species.
- T_e is the electron temperature

If we define a parameter α : $\alpha = n_1/n_e$

This implies: $v_{ph}^2=\frac{\alpha kT_e}{M_1}+\frac{(1-\alpha)kT_e}{M_2}$ for a two species plasma

Two Ways to Measure Ion Acoustic Wave Phase Velocity

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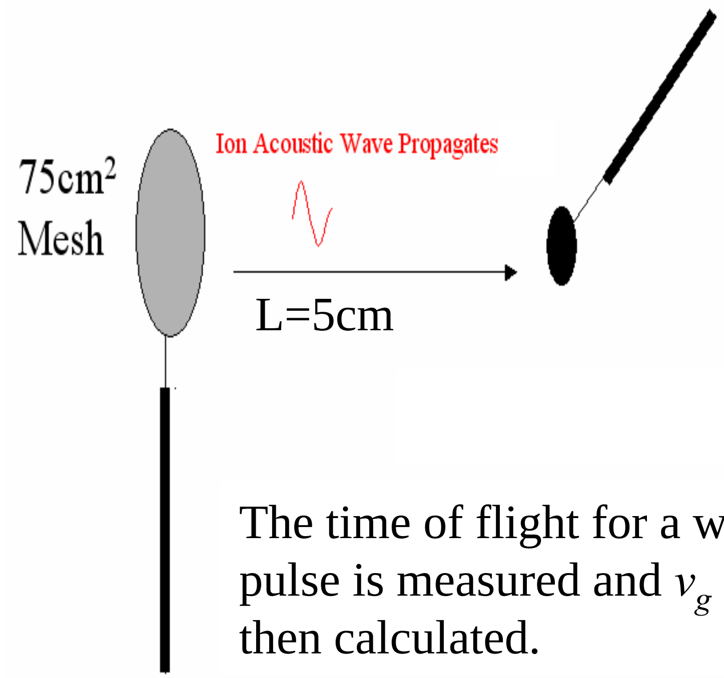
- Method 1:Group Velocity
  - $v_g = d\omega/dk=(c_{s1}+ c_{s2})^{1/2} = v_{ph}$
  - With this method ω and v_g are measured and k is calculated.
  - Sources of Error:
    - *The launch point of the wave pulse may be substantially different from the position of exciter mesh.*
    - *This leads to significant errors in v_g calculations based on the time of flight of the wave pulse.*



The time of flight for a wave pulse is measured and v_g is then calculated.

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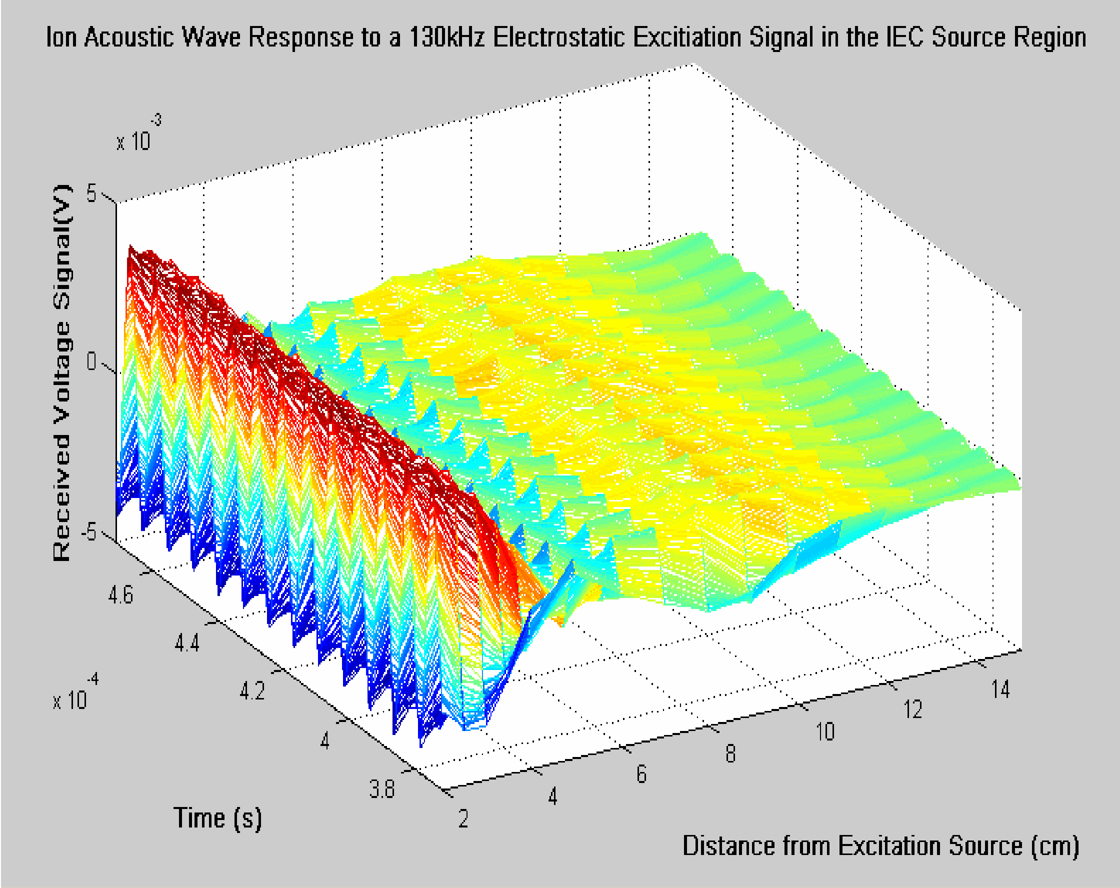
Two Ways to Measure Ion Acoustic Wave Phase Velocity

- Method Two: Direct Phase Velocity Measurement:
  - By moving a negatively biased Langmuir probe through a plasma perturbed by a continuous sine wave, *ω* and *k* are directly measured.
  - v_{ph} can be directly calculated.
  - A high degree of accuracy can be obtained with this method.



3.0eV plasma, 0.34 Pa D_2 pressure, 60V bias on filaments

v_{ph} = *7300 m/s* → min D_3+ fraction 76%±15%

IAW Experiments Using Method 1: D_3^+ in Source Region for Varying Conditions

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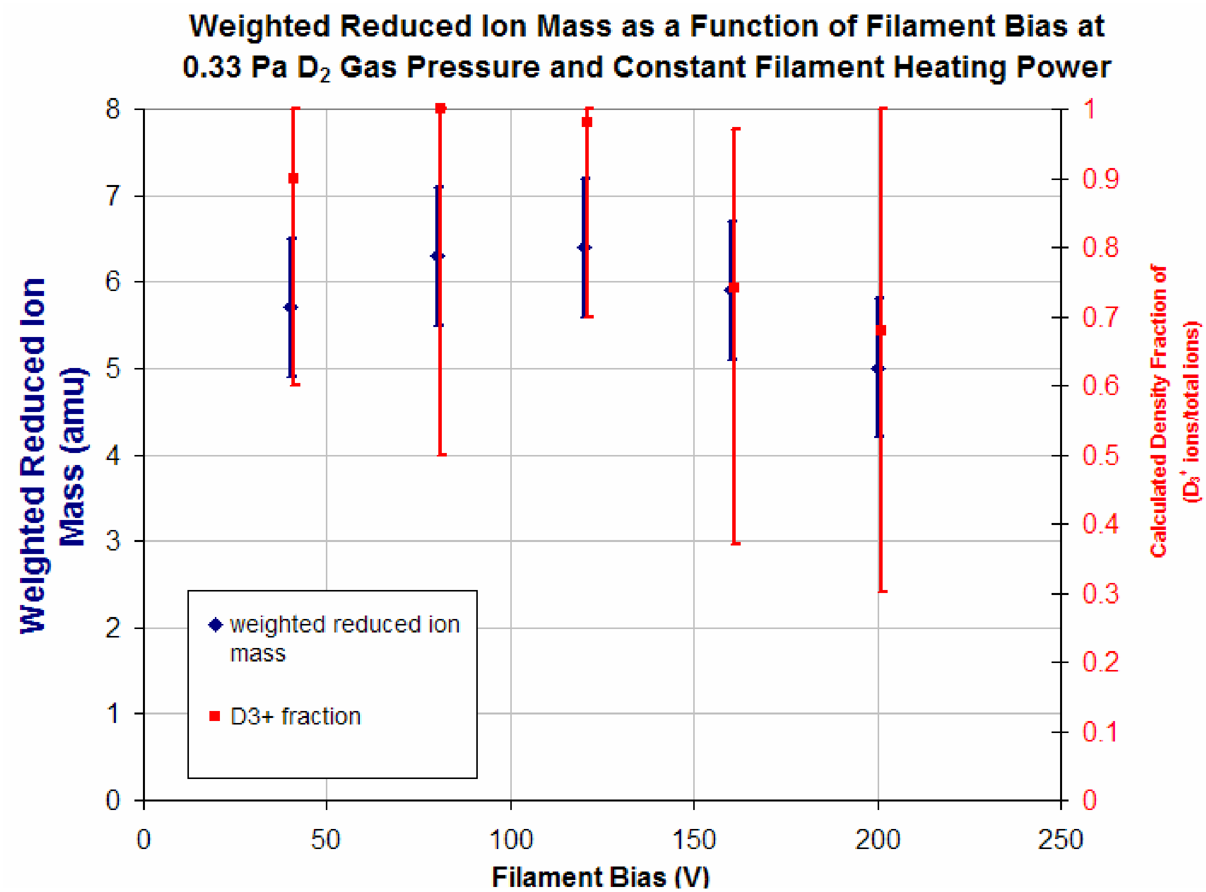
Filament Bias Scan shows constant D_3^+ fraction.

Weighted Reduced Ion Mass
Is defined as:

$$M_R^{-1} = \frac{1}{n_e}\left(\frac{n_{D3}}{M_{D3}} + \frac{n_{D2}}{M_{D2}} + \frac{n_D}{M_D}\right)$$



IAW Experiments Using Method 1: D_3^+ in Source Region for Varying Conditions cont.

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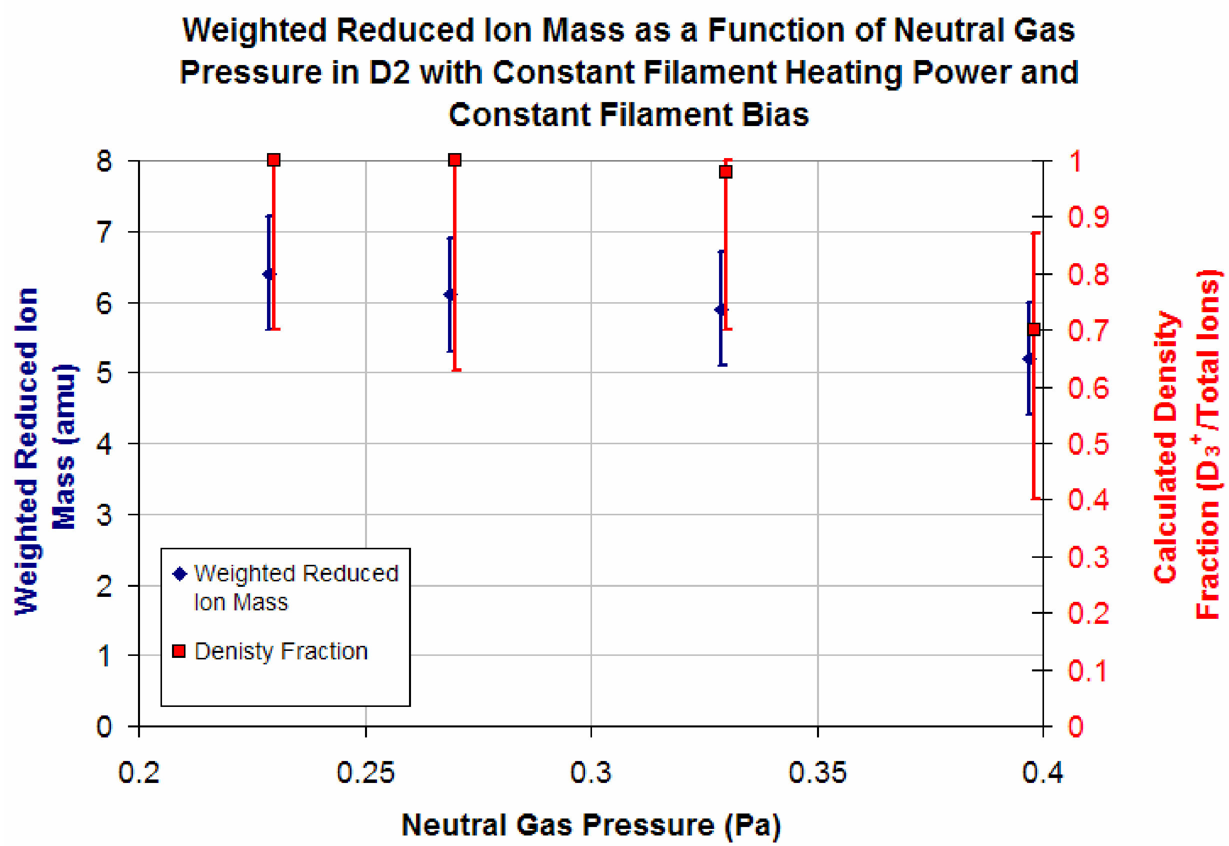
Pressure Scan



Weighted Reduced Ion Mass
Is defined as:

$$M_R^{-1} = \frac{1}{n_e}\left(\frac{n_{D3}}{M_{D3}} + \frac{n_{D2}}{M_{D2}} + \frac{n_D}{M_D}\right)$$

IAW Experiments Using Method 1: D_3^+ in Source Region for Varying Conditions cont.

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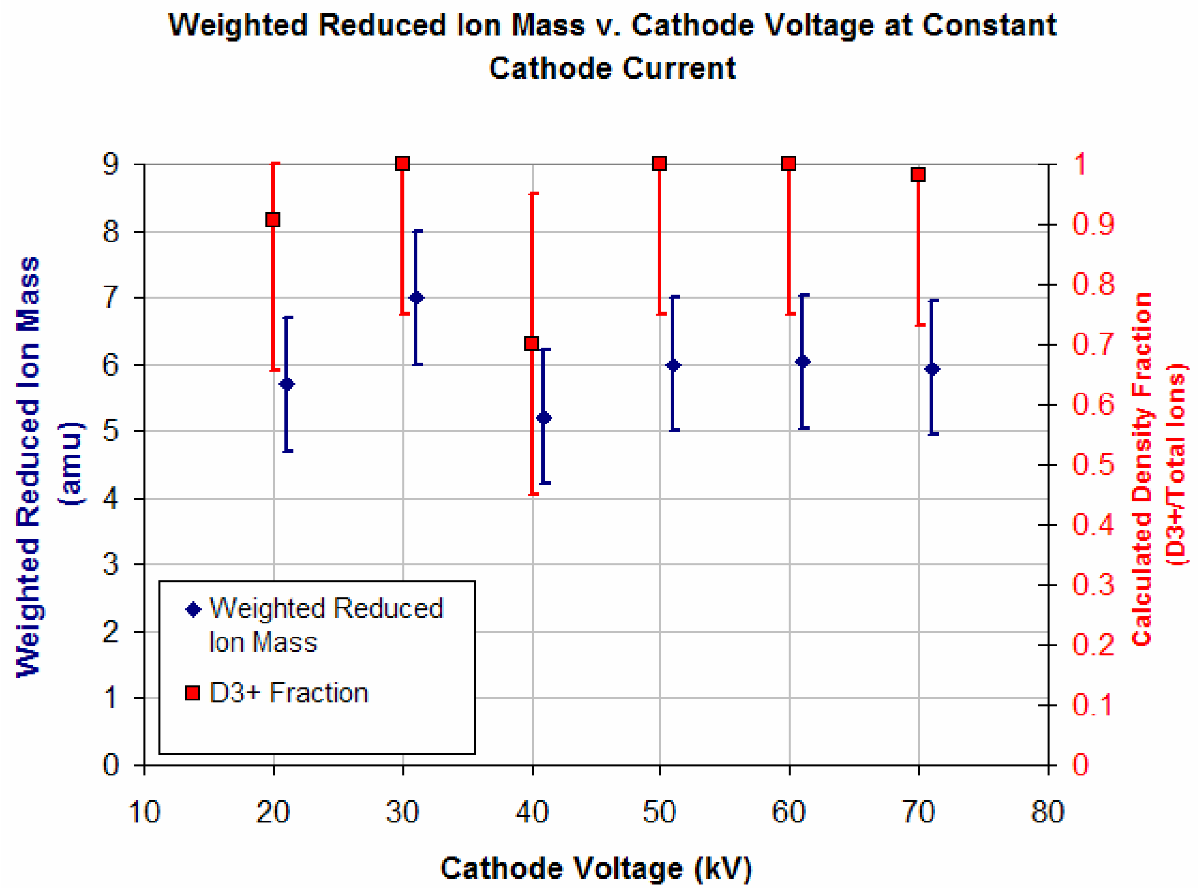
Cathode Voltage Scan

Data indicates D_3^+ concentrations of ~80% with 25% of experimental error, across a range of source conditions



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IAW Experiments with Method 2 Show D_3^+ with Greater Accuracy

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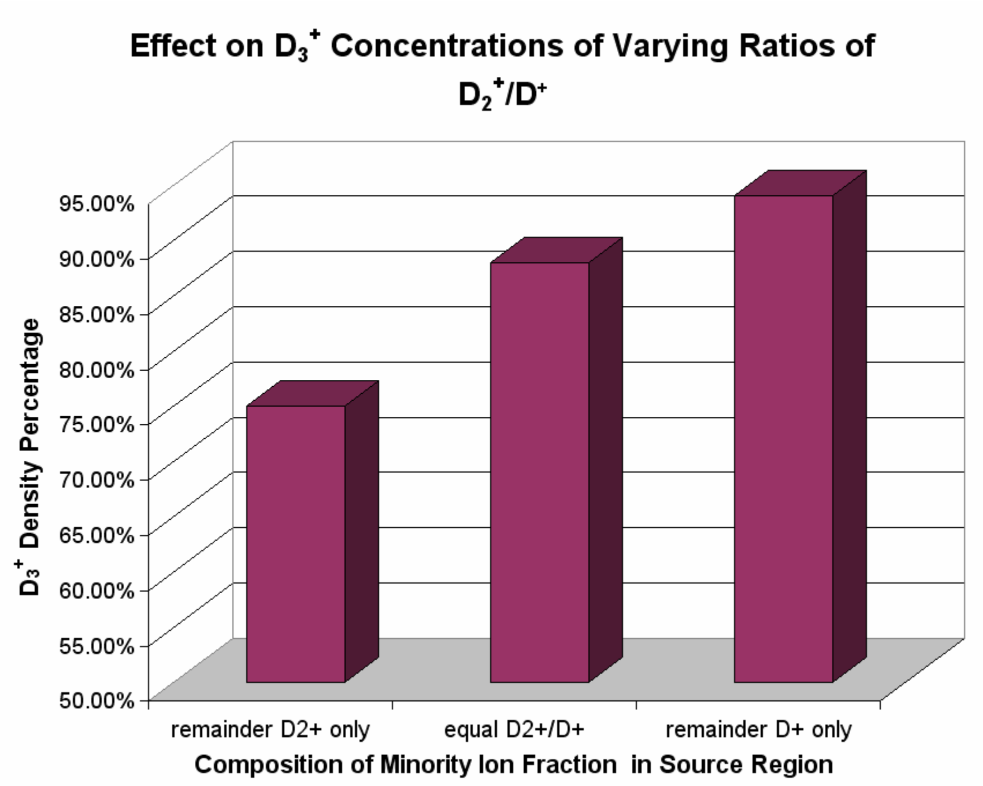
- For standard source plasma conditions Method 2 measures the D_3^+ fraction to within 15%
- The contributions of varying ratios of D_2^+/D^+ ions in the source are shown.



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Conclusions and Future Work

- Ion Acoustic Wave experiments show high concentrations of D_3^+ in the IEC source region for the typical operating regime of the original UW-IEC device.

- Future experiments will involve more complete parametric studies of the source plasma conditions using the method of direct phase velocity measurement.

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QUESTIONS?

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