Measurements of the ion drift velocities in the presheaths of plasmas with multiple ion species

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In 3 steps we describe diode laser based LIF measurements that were the first to test the Bohm Criterion for multiple ion species plasmas.
Thanks to the NSF-DOE Partnership for Basic Plasma Physics for supporting this work!

Team Sheath UW-USD

- Noah’s current student on the project: Mr. Chi-Shung Yip
- His recent PhD’s: Dr. Xu-Wang, Dr. Dongsoo-Lee, Dr. Young-Chul Ghim (finishing at Oxford)
- at USD, Mr. Camron Proctor (‘10), Mr. Tim Welsh (‘14), Mr. Chris Yip (‘14)
Bohm’s criterion: ions must break the ion sound speed in order for quasi-neutrality to give way to space-charge and sheath formation.
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We had to find new LIF schemes for each ion.
Instrument setup is typical (laser, beam-steering, chopper, etalon, wavelength meter, etc..), and all our work has been done with diode lasers since 2000, an evolving technology.

- Diode Laser, 2-Iodine Cell,
- 3-Chopper, 4-Wavemeter, 5-Lock-in,
- 6-Boundary plate
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We had to find new LIF schemes for each of the lasers needed in these experiments, Ar was first.

Review of Scientific Instruments

To “prove” a new LIF scheme one must first 1) find one, 2) see if anyone else is using it (that’s good), and 3) try it out.

Checklist for new LIF scheme

- find a well populated (metastable) state with
- an accessible (via dl) short lived excited state that
- has one dominant decay channel which
- has a wavelength that hits the sweet spot of detector (pmt-blue is best)
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Xenon ion laser-induced fluorescence using a visible tunable diode laser near 680nm, G. Severn, D. Lee, and Noah.
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in Ar+Xe plasmas, would Ar+ be sub-Bohm? Yes!

Finally, with 2 lasers: the generalized Bohm Criterion is satisfied for weakly collisional plasmas with comparable ion densities.

Measurements of Ar$^+$ and Xe$^+$ velocities near the sheath boundary of Ar$^+$-Xe plasma using two diode lasers, D. Lee, N. Hershkowitz, and G. Severn, Appl. Phys. Lett. 91, 041505 (2007)
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![Graph showing ion velocity and plasma potential vs distance](image)

**Measurements of Ar$^+$ and Xe$^+$ velocities near the sheath boundary of Ar$^+$Xe plasma using two diode lasers, D. Lee, N. Hershkowitz, and G. Severn, Appl. Phys. Lett. 91, 041505 (2007)**

was Bohm’s Criterion satisfied?

$$\sum_i \frac{n_{io} C_i^2}{n_{eo} V_{io}^2} = 0.97 \pm 0.5$$
Finally, with 2 lasers: the generalized Bohm Criterion *is* satisfied for weakly collisional plasmas with comparable ion densities.

![Graph showing ion velocity and plasma potential as a function of distance.](image)

*Measurements of Ar+ and Xe+ velocities near the sheath boundary of Ar+Xe plasma using two diode lasers, D.


But something was wrong... we observed ‘flow locking’ which cannot be explained by ion-neutral collisions.
Breakthrough: Baalrud et al. predict Ion-Ion two stream instability, turns on for thermal ions $\Delta V \geq V_{\text{crit}}$

S. D. Baalrud and C. C. Hegna, *Determining the Bohm criterion in plasmas with two ion species* Physics of Plasmas 18, 023505 (2011)

$$\Delta V_c = -\frac{3}{2} |v_{T2} - v_{T1}| + \sqrt{\frac{1}{2} \left( v_{T1}^2 + v_{T2}^2 + \frac{n_2 T_1}{n_1 T_2} v_{T1}^2 + \frac{n_1 T_2}{n_2 T_1} v_{T2}^2 \right)}$$

Xenon drift velocities measured by LIF are marked by the squares, Argon velocities measured by LIF are marked in circles, solid line is the prediction curve and the dash dotted line is the common sound velocity.

This was verified in our paper, “Experimental Test of Instability-Enhanced Collisonal Friction for Determining Ion Loss in Two Ion Species Plasmas”, Yip, CS; Hershkowitz, N; Severn, G. Phys Rev Lett. Vol.104 Iss:22 #225003 (2010)
We began new work with KrII in order to try the 3 ion species sheath formation problem, but also relevant to new work in Hall Thruster plasmas.
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Because the main isotope shifts are of order of the room temperature Doppler Broadening \(0.7\, \text{GHz}\), we need to perform noise tolerant deconvolution.

### Basic Digital Algorithm

\[ Ax = b, \; (A \text{ is } n \times n \text{ matrix}) \]
\[ x \text{ (ivdf)} \]
\[ b \text{ (LIF)} \]
\[ \therefore x = A^{-1}b. \]
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**Tikhonov Regularization**

Perform singular value decomposition of $A$, $A = U\Sigma V^*$, 
filter out contributions of the tiniest singular values $\sigma_i$ using a filter factor, $f_i$ 
with a 'regularization parameter', $\alpha$; 
$$f_i = \frac{\sigma_i^2}{\sigma_i^2 + \alpha^2},$$
yielding a modified matrix, $\Psi$, giving 
$$A^{-1} = V\Psi^{-1}U^*$$ 
that minimizes $Ax - b$ element by element.
Progress: the deconvolution gives a recovered ion velocity distribution function (IVDF) closer to room temperature 650K +/- 200K.
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**Concerns**

But deconvolved IVDF looks too much like LIF signal....
First test of Bohm Criterion w. multiple ion species

New dLIF schemes to perform the measurements

New way of thinking of sheath formation
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AND THANKS FOR YOUR ATTENTION!