First laser-induced fluorescence measurements of argon and xenon ion velocities near the sheath boundary in 3 ion species plasmas

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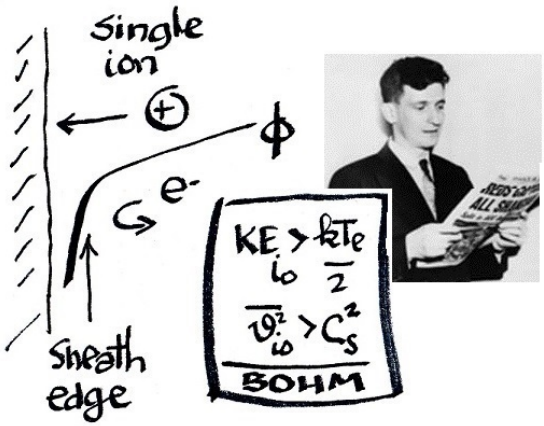
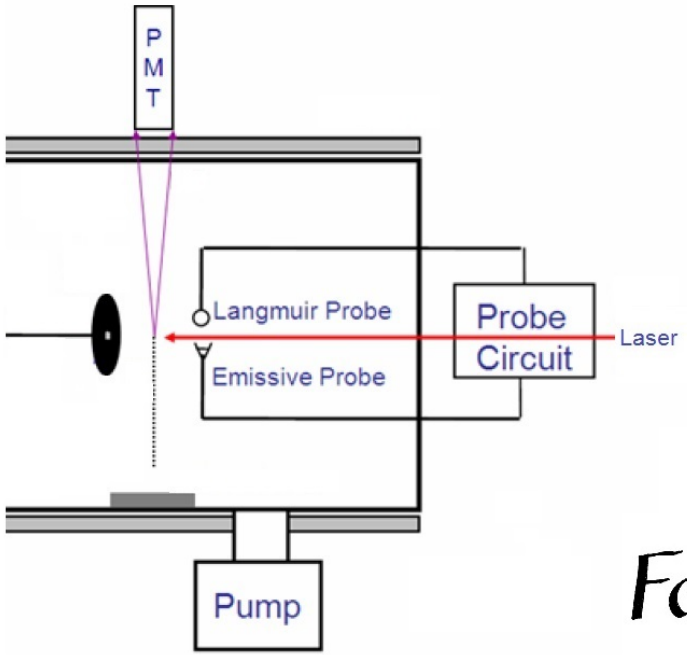
11 October 2016

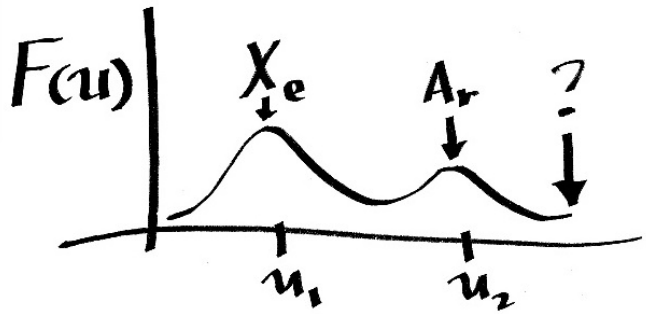
This talk is about Bohm's Criterion, and validating experiments in multiple ion species plasma, performed for the first time



Bohm's Criterion



experimental details



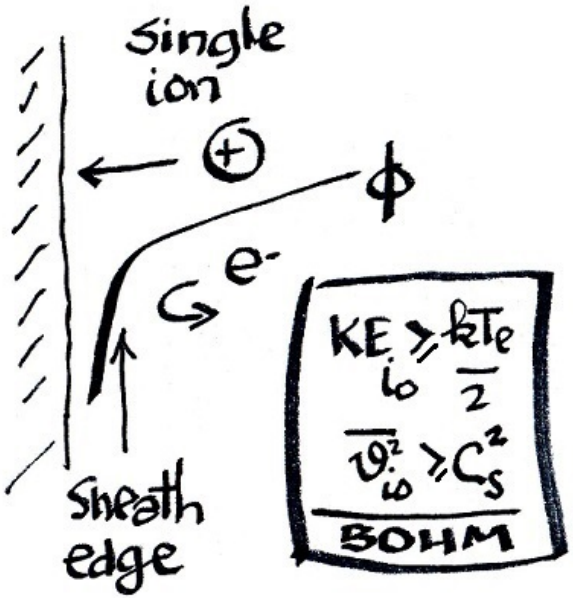
NEW RESULTS W. 3 ION SPECIES

Thanks to UW-USD-Iowa collaborators and DOE-NSF Partnership for Basic Plasma Physics

Team Sheath UW-USD-Iowa

- Noah's recent doctoral student, staff scientist: Dr. Chi-Shung Yip top left,
- latest students at USD, Tim Welsh ('14), Chris Yip ('14), Quinn Pratt ('17)
- Scott Baalrud (U. Of Iowa) 2015 NSF Career Award winner

Bohm's criterion (c. 1949): ions break sound barrier so quasi-neutrality can break down to form a sheath at the plasma boundary



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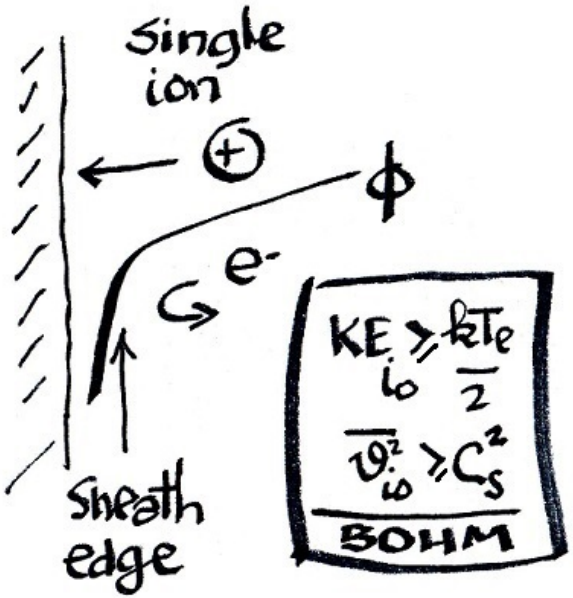
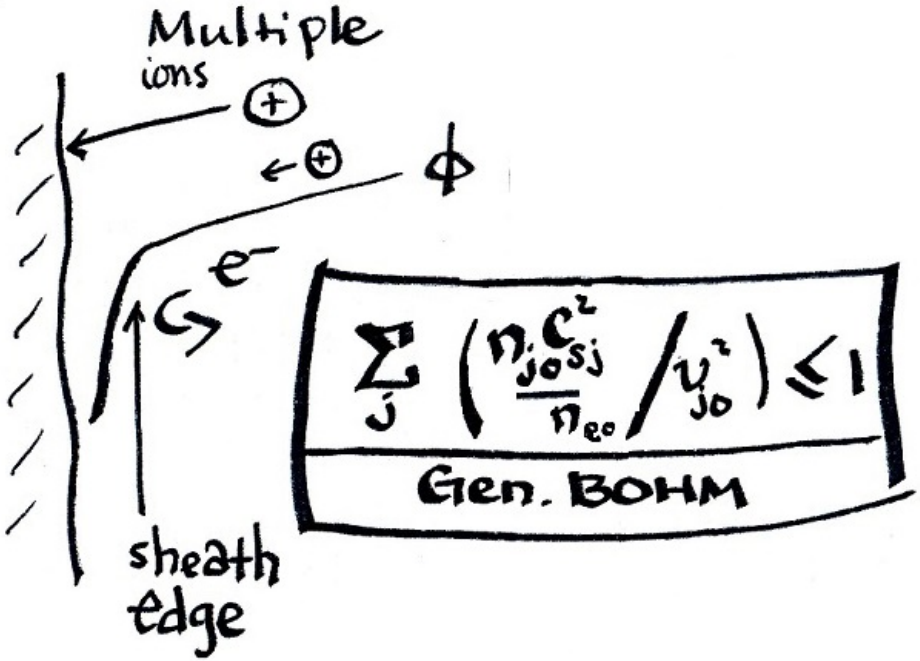
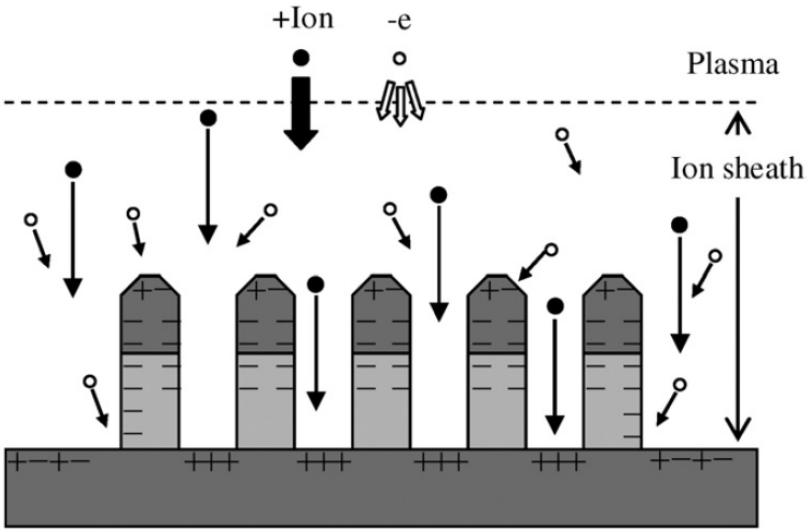


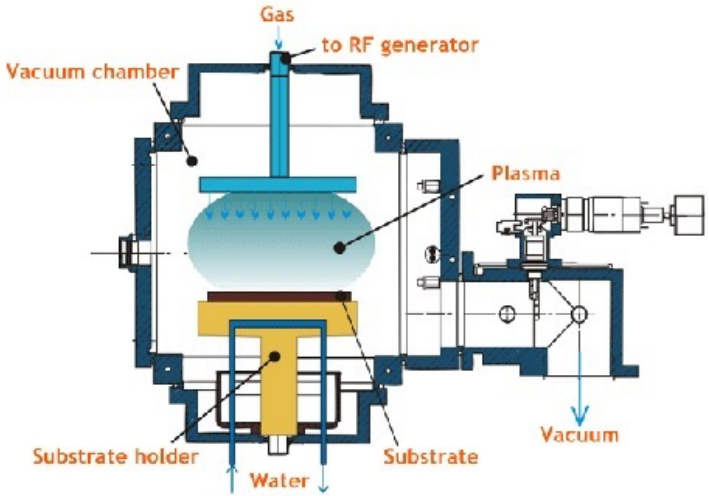


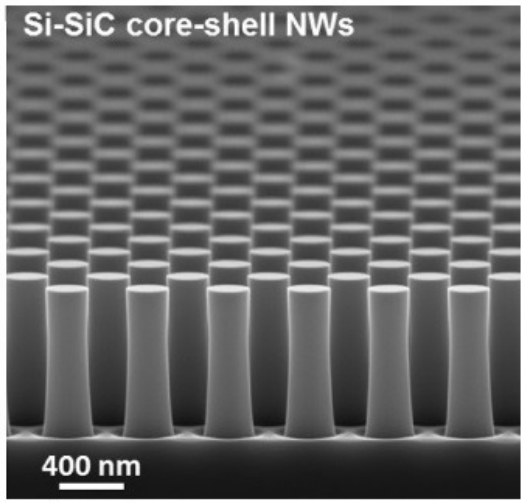
first results, Sheridan, Goree, & Goeckner, verified $v_{io} > C_s$ in the sheath. Phys. Fluids B 4 (1992) 1663; GBc: K.-U. Riemann, IEEE Trans. Plasma Sci. 23, 709 (1995).

So what-Who cares-Big deal???

Practical Answers: if you could patent 'the sheath', you'd make a lot of money in VLISI-ULSI, and it's important in divertor plasma physics







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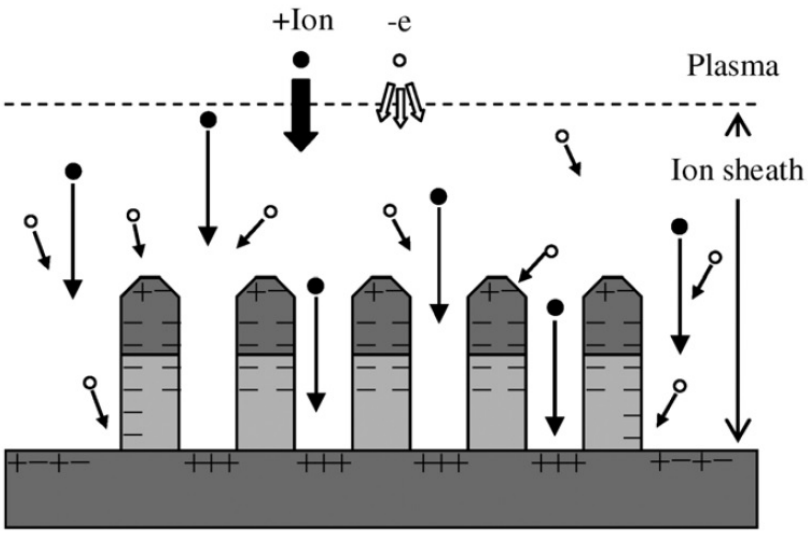
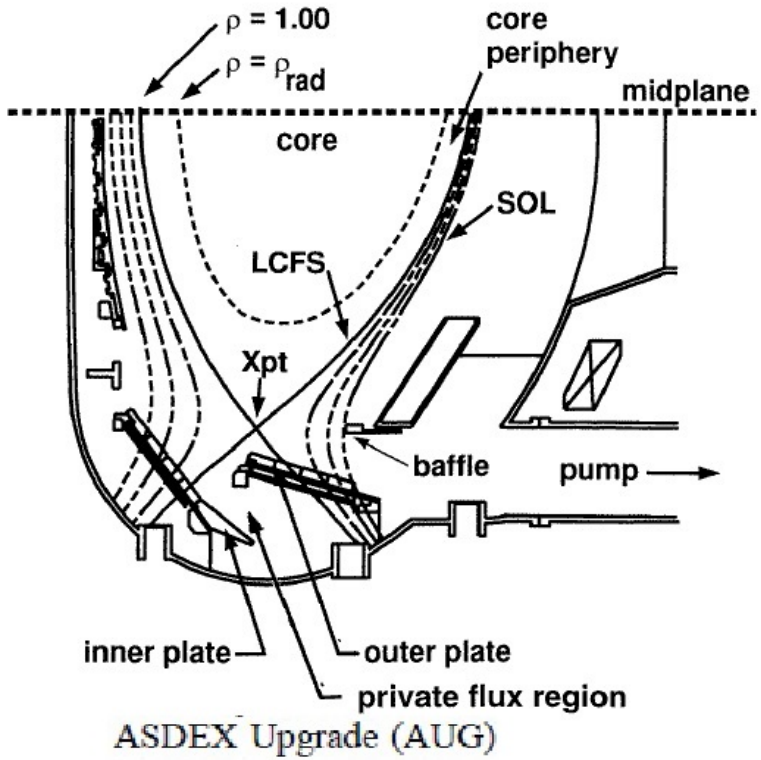
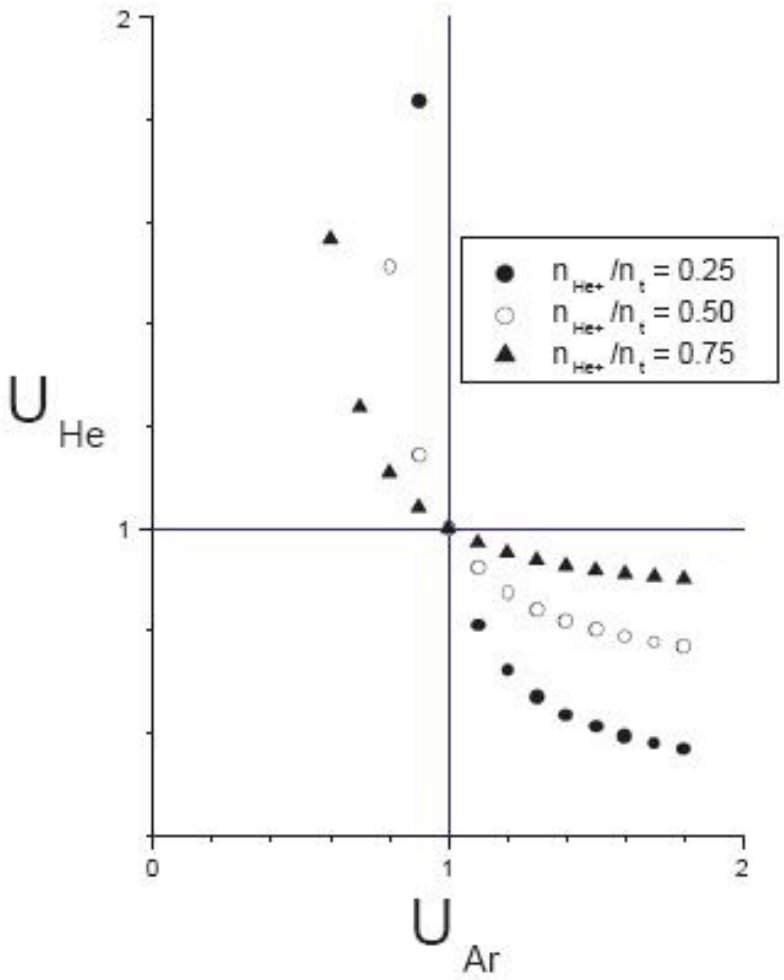




ASDEX Upgrade (AUG)

2012 Plasma Roadmap, Samukowa et al., J. Phys. D: Appl. Phys. 45 (2012) 253001 ***all such plasma systems are multiple ion species plasmas***

HOW DOES BOHM WORK for 2, 3, n ion species? Validation experiments are still new!



Multiple-species Bohm Criterion (GBC) has a continuum of solutions

- $U_i \equiv v_{io}/C_i$, $GBC \Rightarrow \sum_i \frac{n_{io}/n_{eo}}{U_i^2} \leq 1$,
- simple solution #1, $U_i = 1$
- simple solution #2, $U_i = U_j \sqrt{\frac{M_i}{M_j}}$

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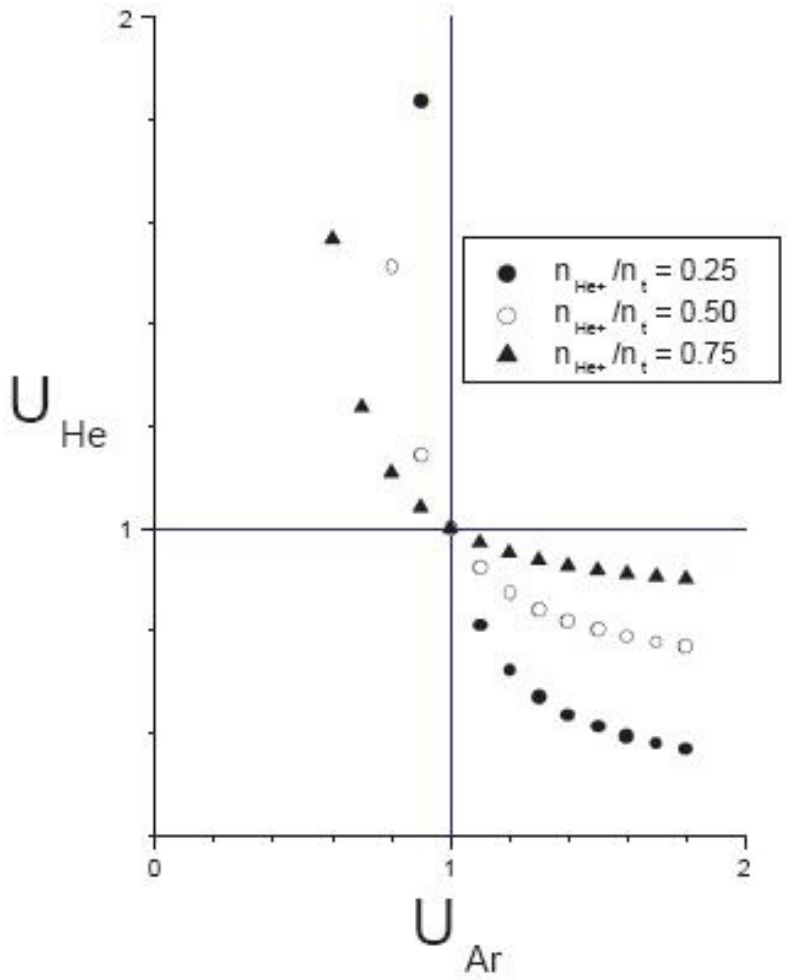

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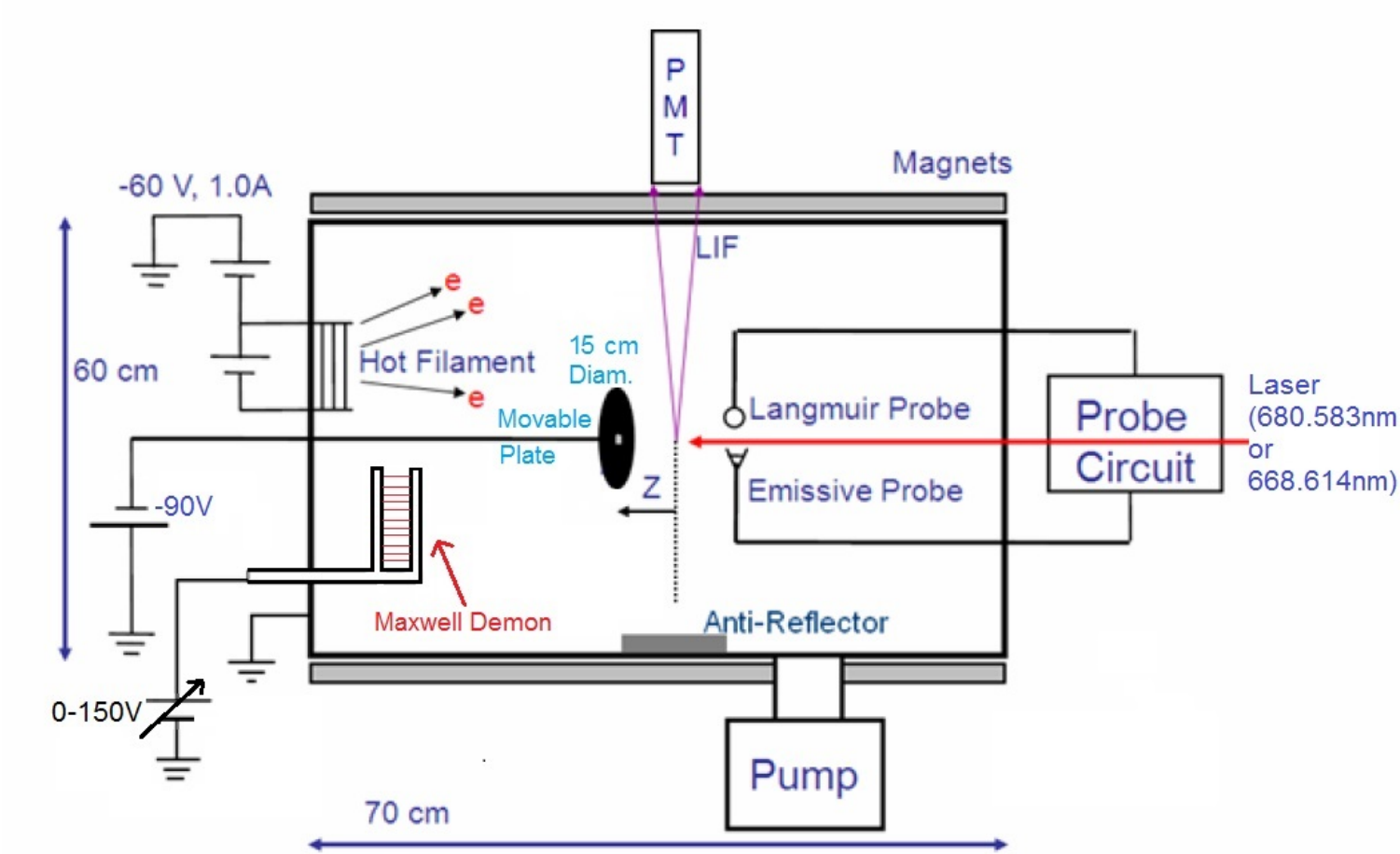
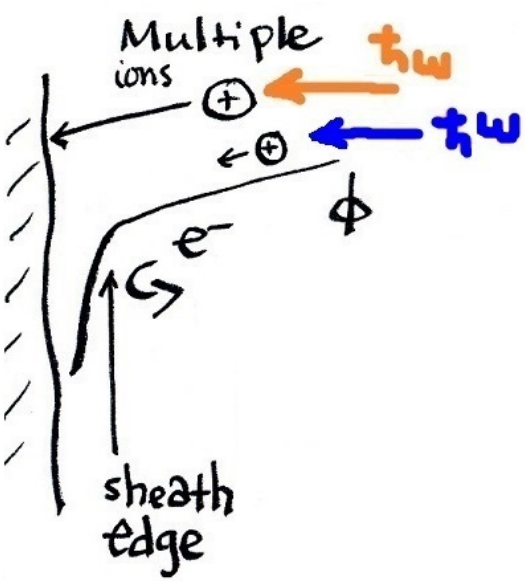
- IF $n = 3$, U_i is Typically Neither!

experimental details–2nd part



wont treat emissive probe measurements that locate the sheath edge, will treat Laser-induced fluorescence (LIF) measurements

IVDF is created from LIF signal through a change of variables using the first order Doppler-shift



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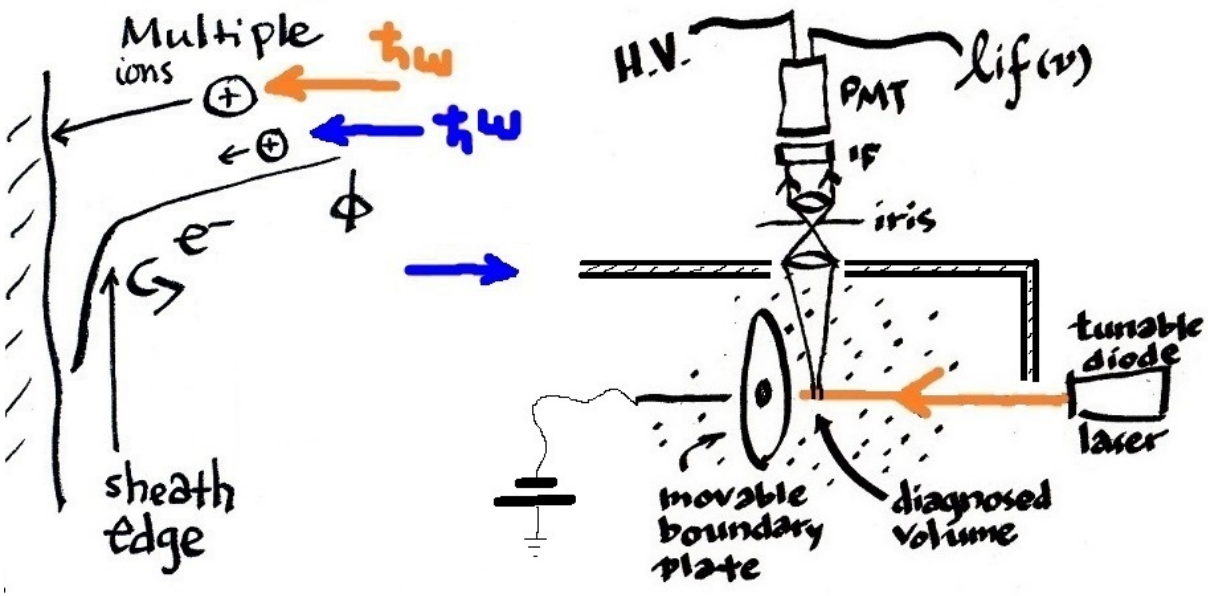

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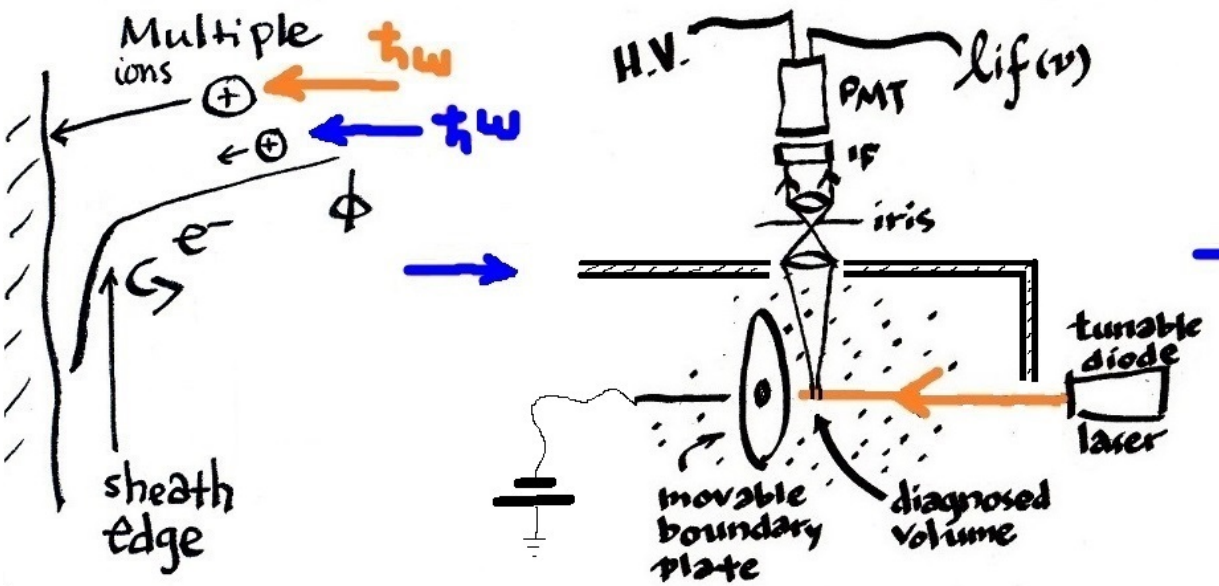

$$\nu_{ik} \approx \nu_0 + k_l \cdot v$$

$$v_z = \lambda_l \Delta\nu$$

$$\langle v_z^n \rangle = \frac{\int_{-\infty}^{+\infty} v_z^n f(v_z) dv_z}{\int_{-\infty}^{+\infty} f(v_z) dv_z}$$

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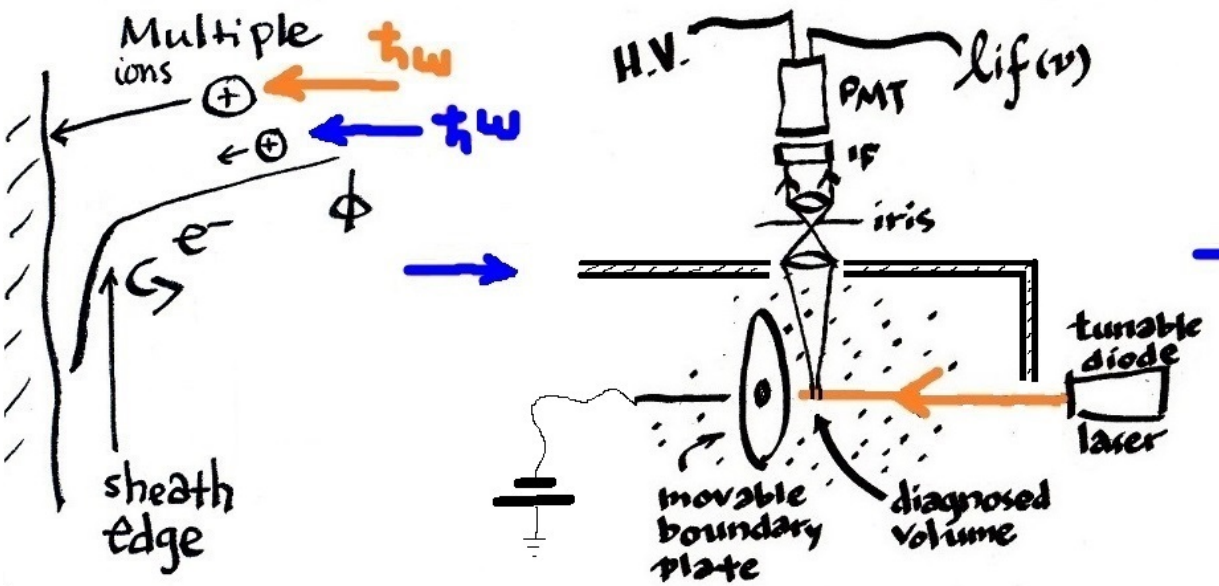

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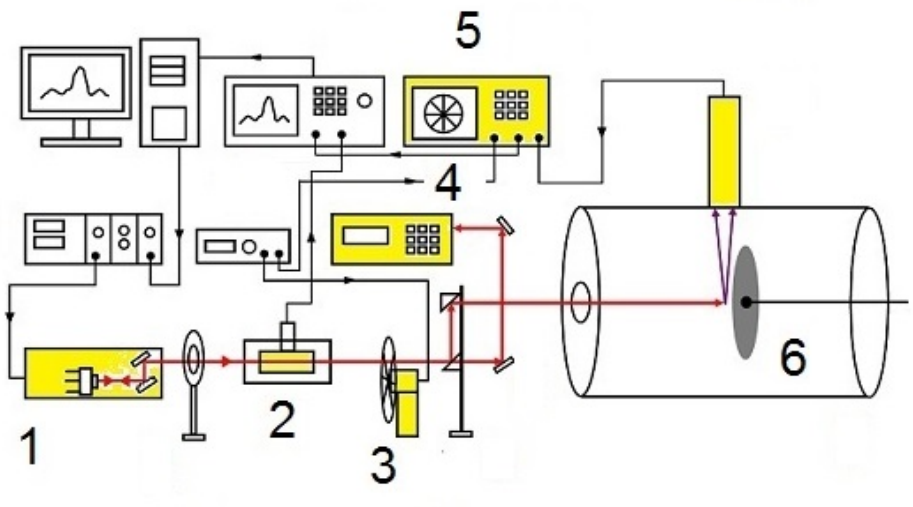
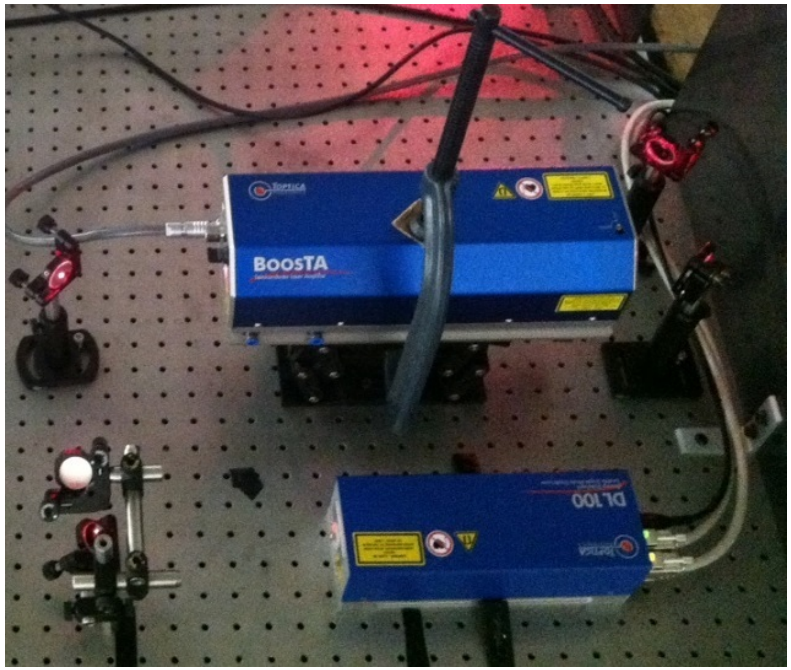
NOTE POSITIVE EXPONENT!!

Typical setup now involves a MOPA laser system: a 'seed' laser optically amplified

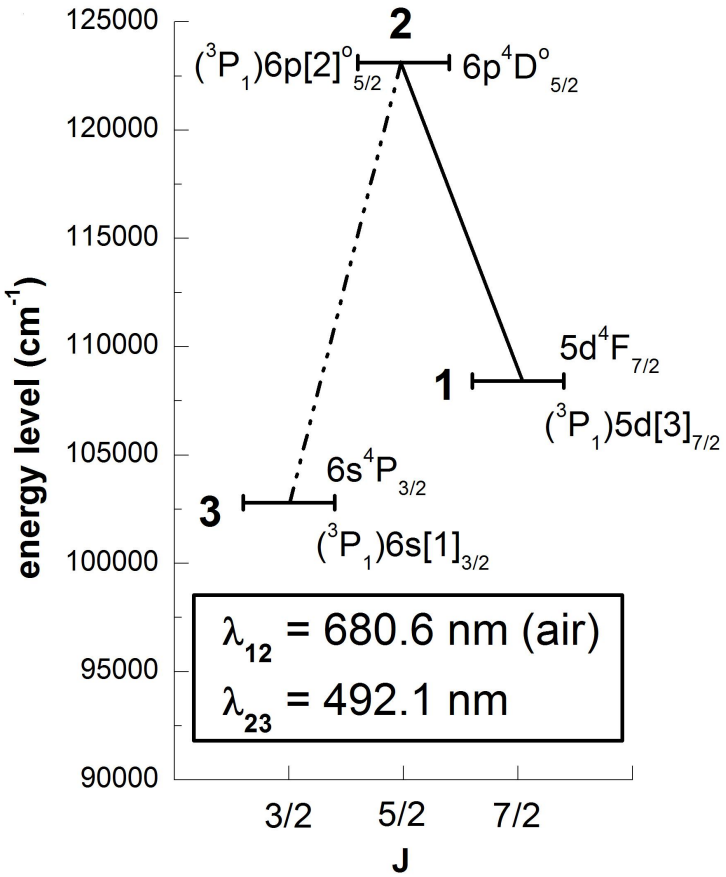


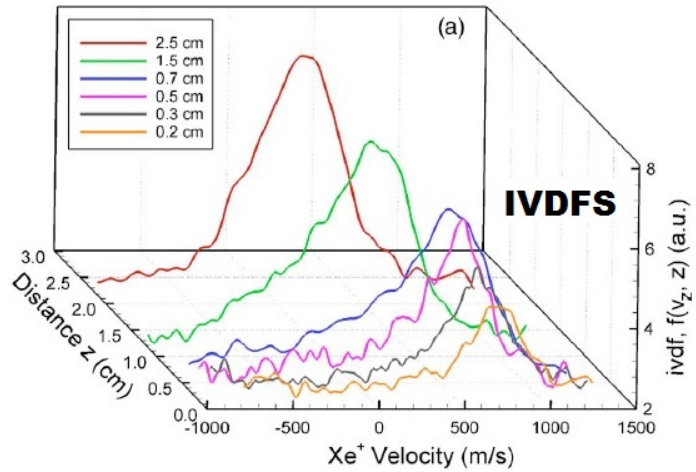
1-Diode Laser, 2-Iodine Cell,
3-Chopper, 4-Wavemeter, 5-Lock-in,
6-Boundary plate

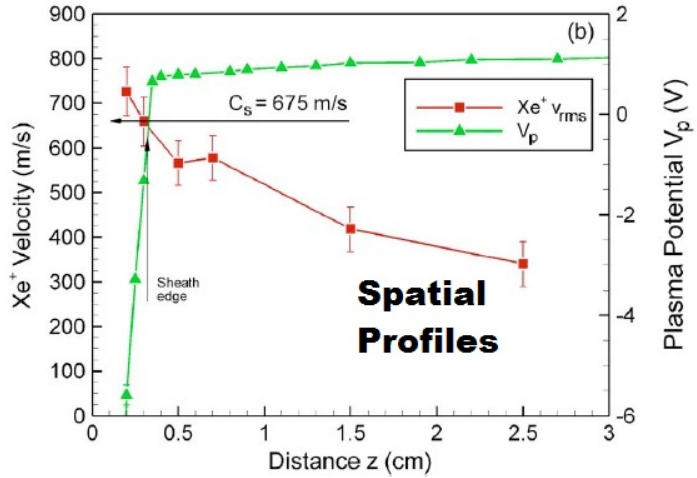


Bohm Criterion is validated in XeII

as with ArII, positive moments!

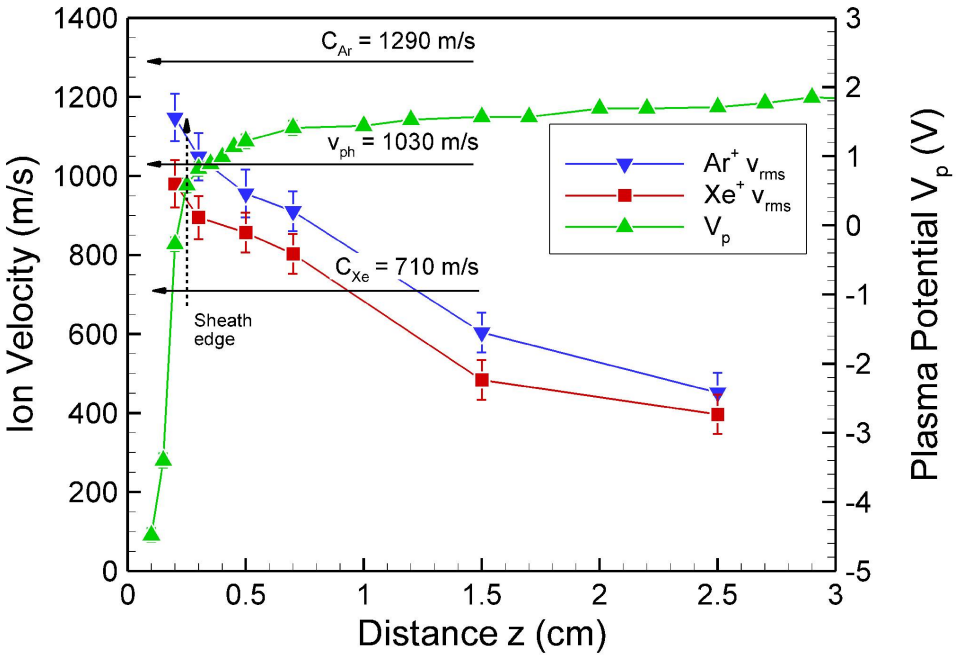






G.D. Severn, et al., Rev. Sci. Instrum. **69** 10 (1998), Severn et al., Phys. Rev. Lett. **90** 1450001 (2003), G. Severn, et al., Rev. Sci. Instrum., **78** 116105 (2007), D. Lee, et al., Appl. Phys. Lett. **91**, 041505 (2007)

The first validation experiment of the generalized Bohm Criterion (gBC) was successful



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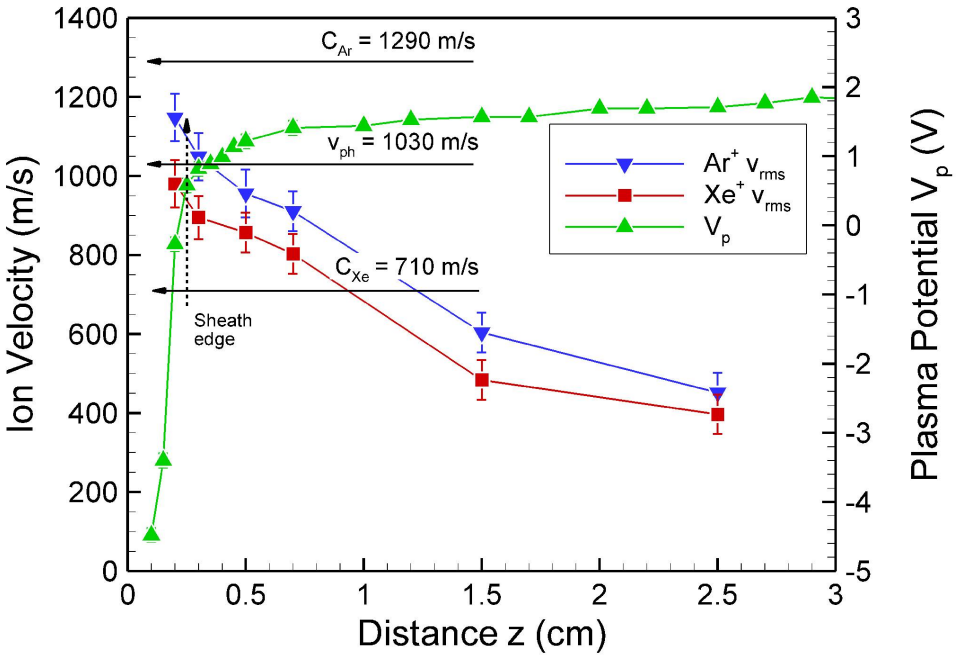
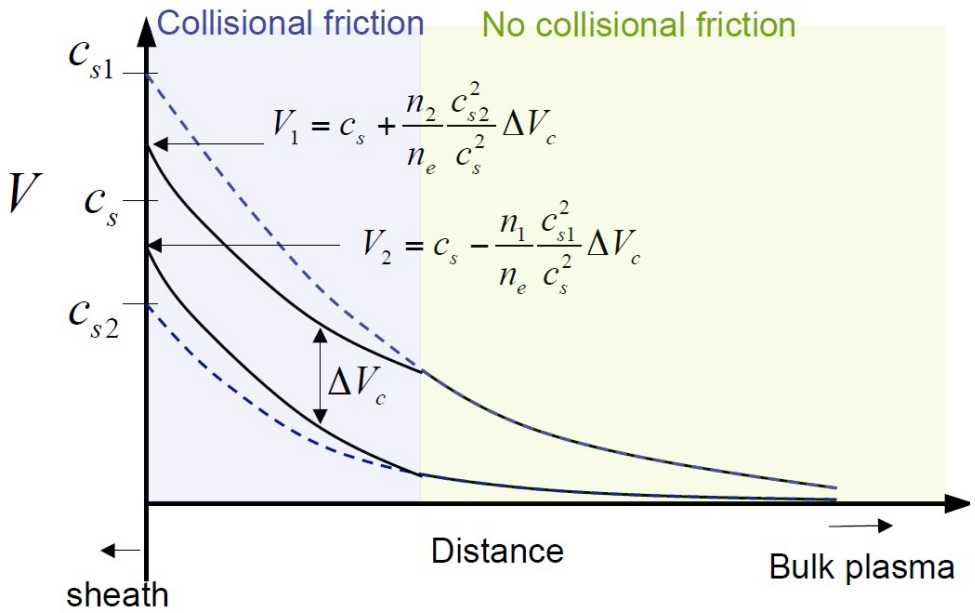


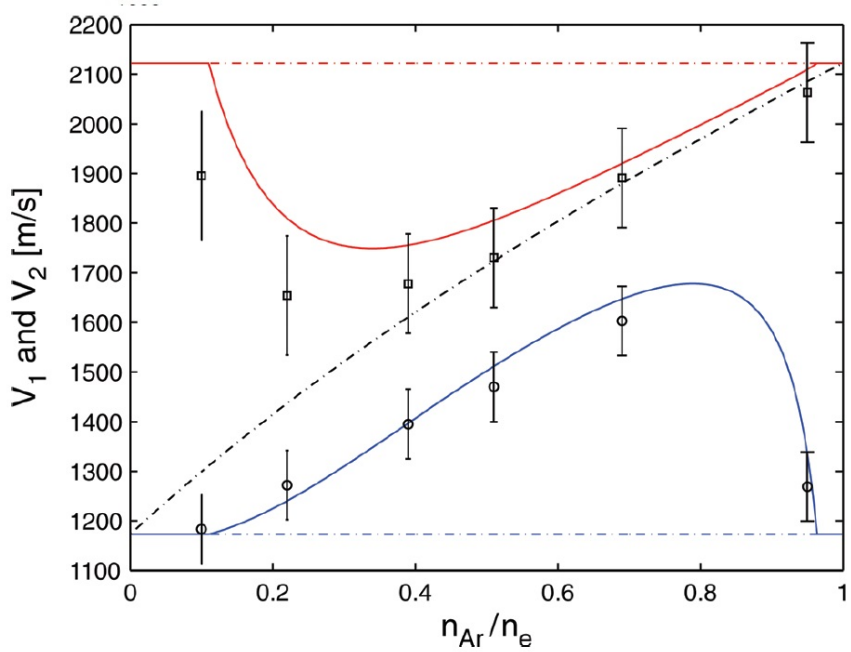
Bohm's Criterion was satisfied

- $\sum_i \frac{n_{io} C_i^2}{n_{eo} v_{io}^2} = 0.97 \pm 0.5$
- velocity 'locking' $\Rightarrow$ Instability Enhanced Collisional Friction (IEF)

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)

Baalrud et al. predict the IEF, turns on for thermal ions $\Delta V \geq V_{crit}, \rightarrow$, kinetic Bohm Criterion depends on ion flow

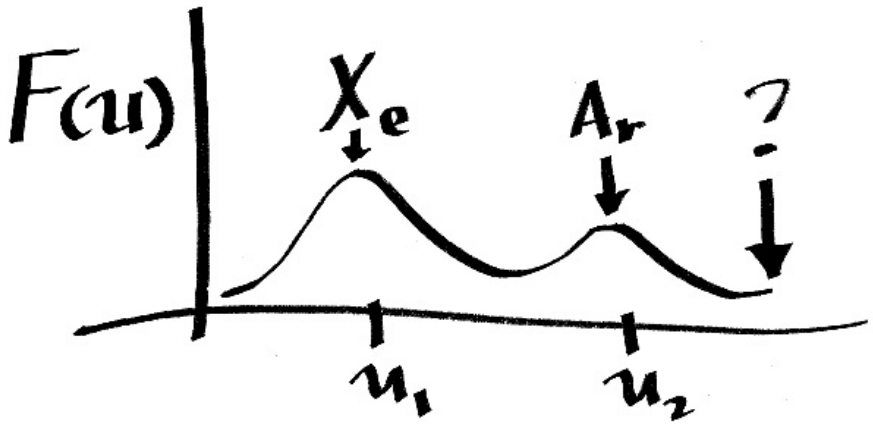




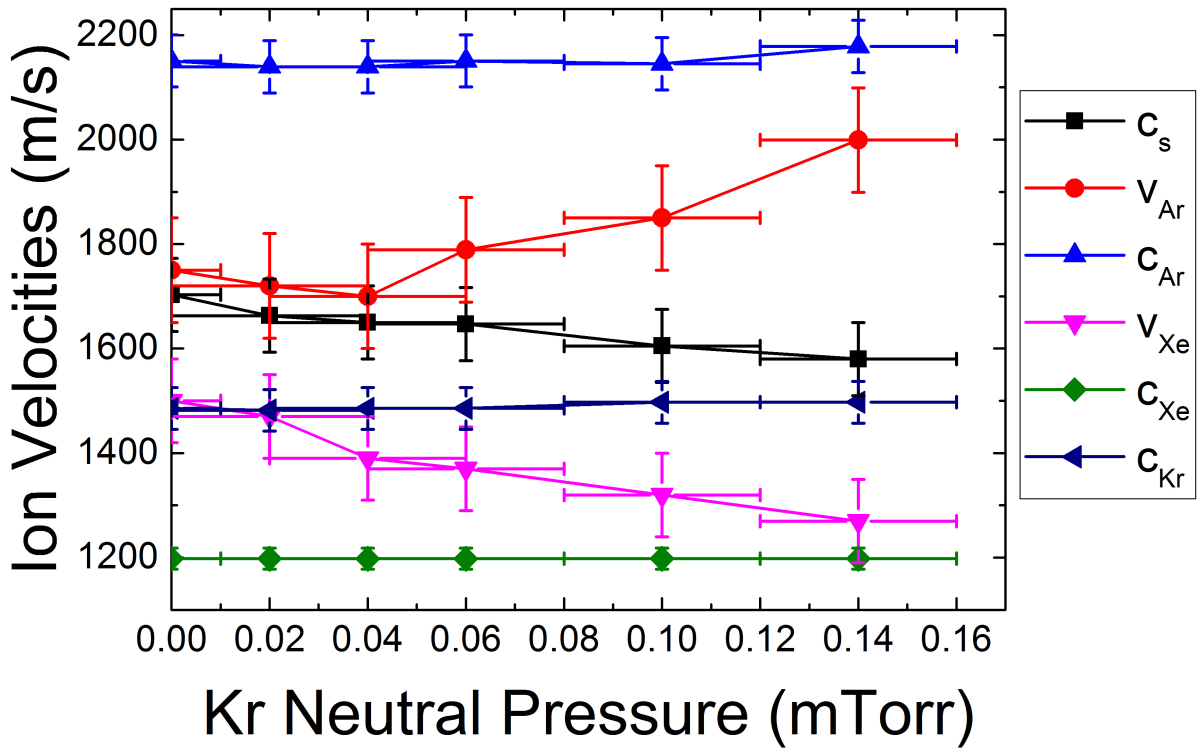
$$\Delta V_c^{\mathrm{kin}} \approx -\frac{3}{2}|v_{T2} - v_{T1}| + \sqrt{\frac{1}{2}\left(1 + \frac{n_2 T_1}{n_1 T_2}\right)\left(v_{T1}^2 + \frac{n_1 T_2}{n_2 T_1} v_{T2}^2\right)}$$

S. D. Baalrud and C. C. Hegna, Physics of Plasmas 18, 023505 2011, Hershkowitz, et al. Physics of Plasmas 18 0000000 2011

New results with 3 ion species plasma–last part

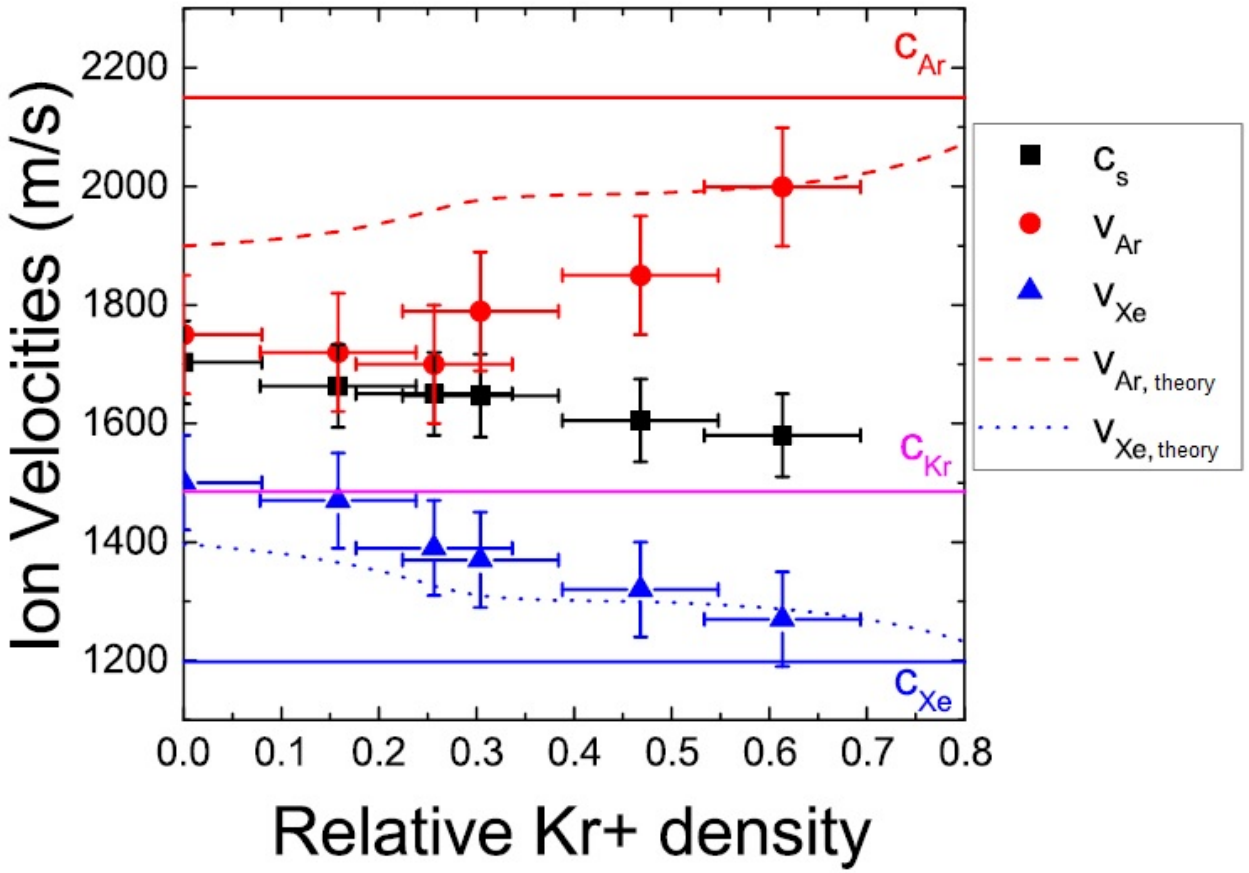


Now adding a third ion species, intermediate mass (Ar, Kr, Xe): does IEF bring ions to a common speed at the sheath edge? NO!!??



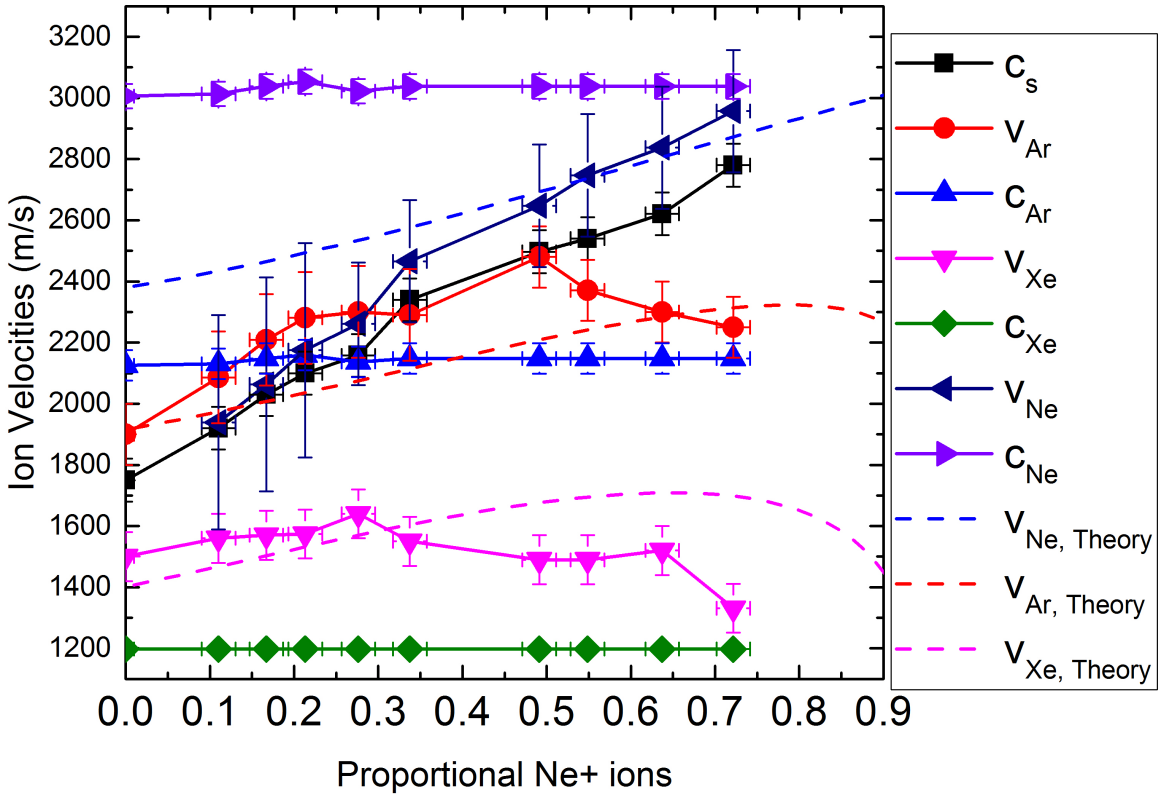
$P_{Xe} = 0.04 mTorr$, $P_{Ar} = 0.1 mTorr$,fixed, P_{Kr} was varied, with $I_d = 2A$, and kT_e $2eV$.

Varying Kr+ density, we find that $C_s < \langle V_o \rangle_{Ar} < C_{Ar}$, as if adding Kr^+ gradually turns off IEF



$T_e = 1.95 \pm 0.08eV$, and argon and xenon neutral pressures are fixed at 0.1mTorr and 0.04mTorr respectively–Yip et al., Phys. Plasma 23 050703 (2016); G-H Kim, et al., J. Phys. D: Appl. Phys. 48 (2015) 225201

We tried a less massive 3rd ion (Ne) to see if the IEF would always remain active, which it does, but then ultimately shuts off gradually too



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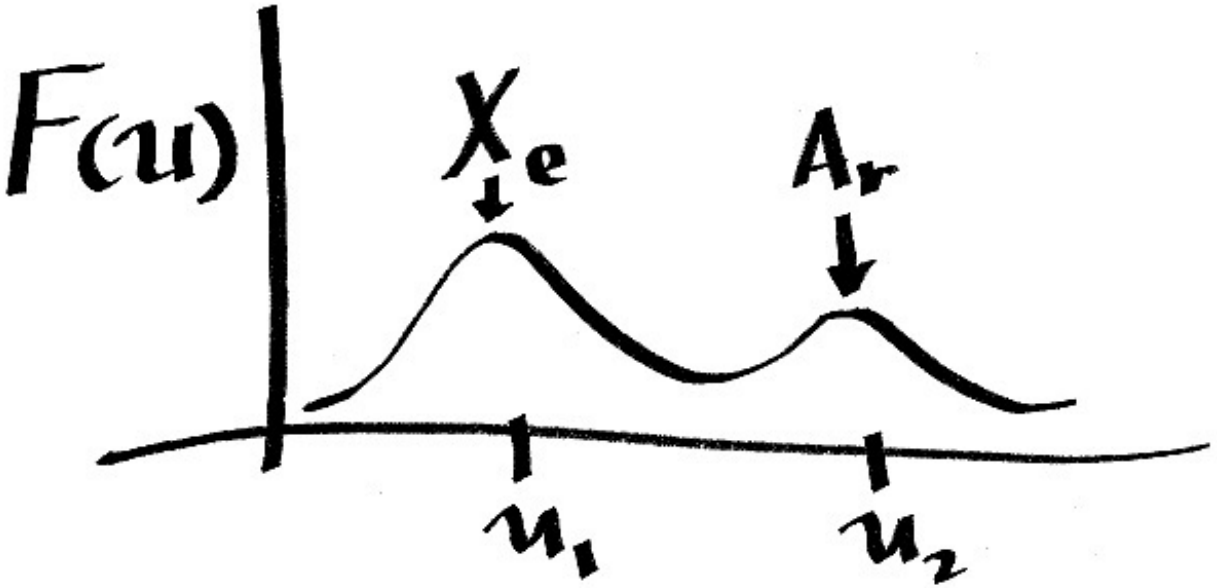
Heuristically, Penrose criterion $\Rightarrow$ if $F(u)$ has one maxima there are no growing modes, but if there are minima we can get exponentially growing modes



$$F(u) = \sum_j \frac{\Omega_{pj}^2}{\omega_{pe}^2} f_j(u)$$

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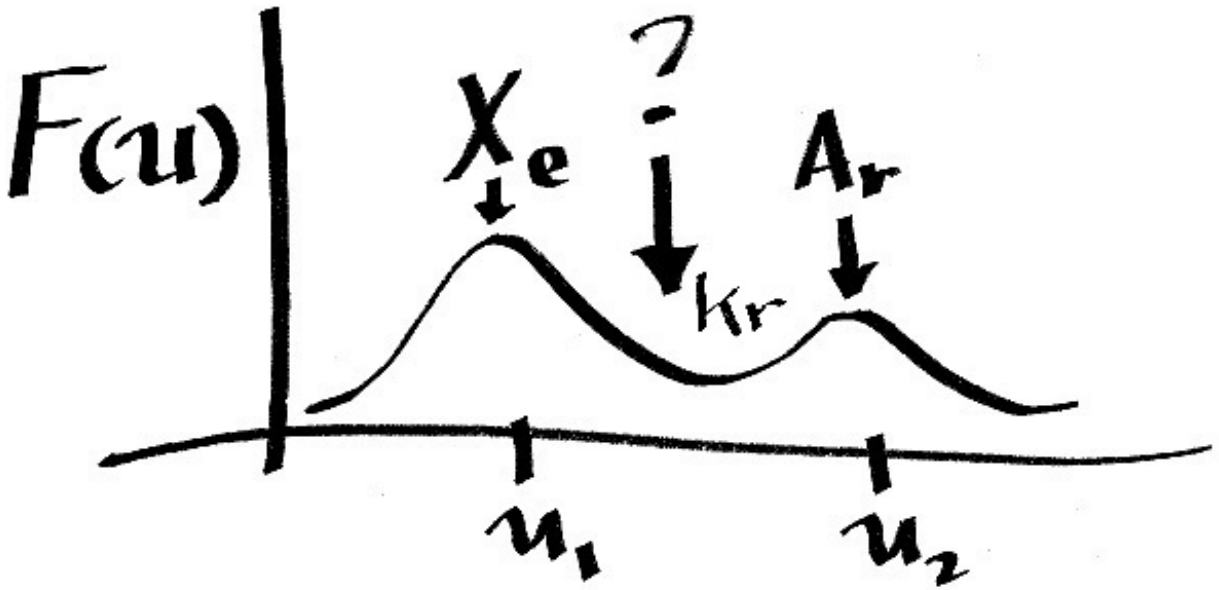

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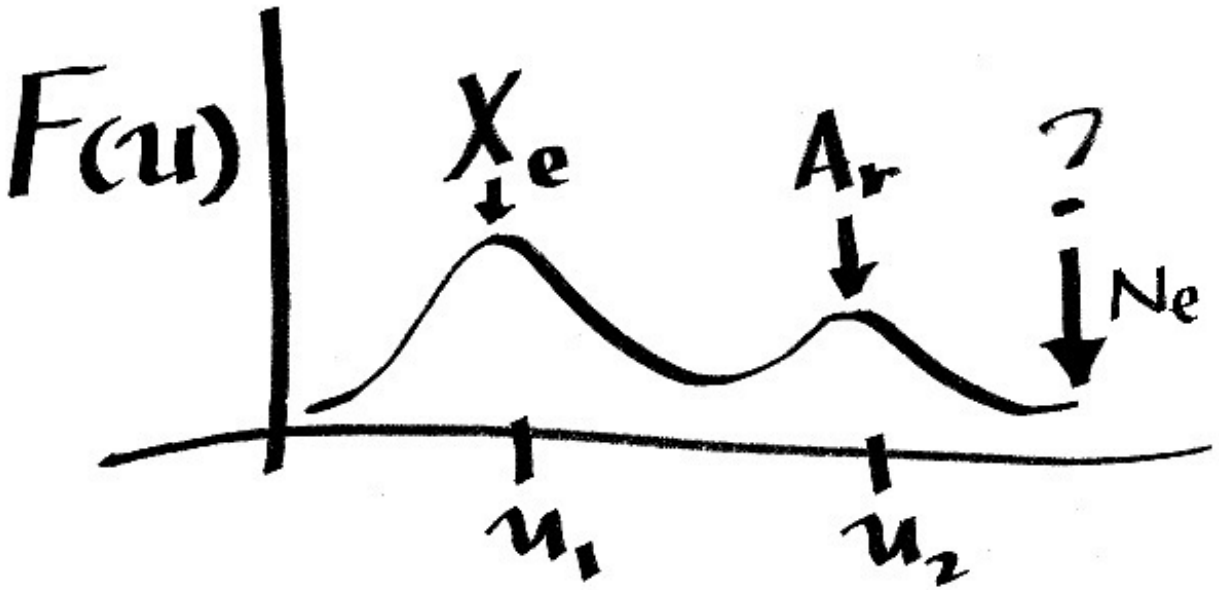

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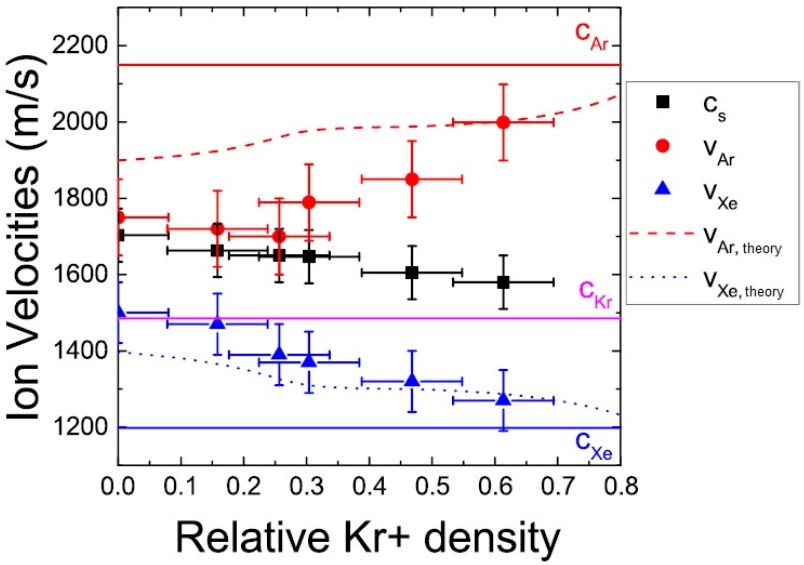
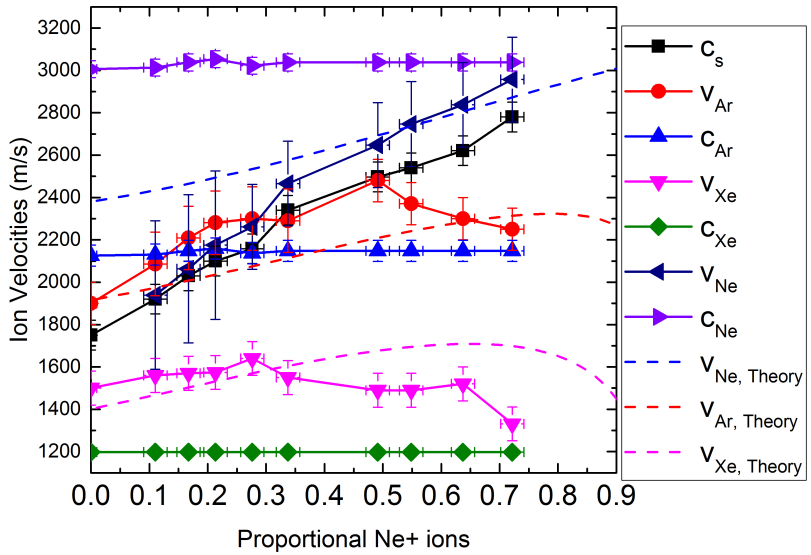
3 ion species problem: under most circumstances the ions neither fall out of the plasma at the system sound speed, nor their Bohm speeds-central point of talk





THESE RESULTS ARE NOT SIMPLE....

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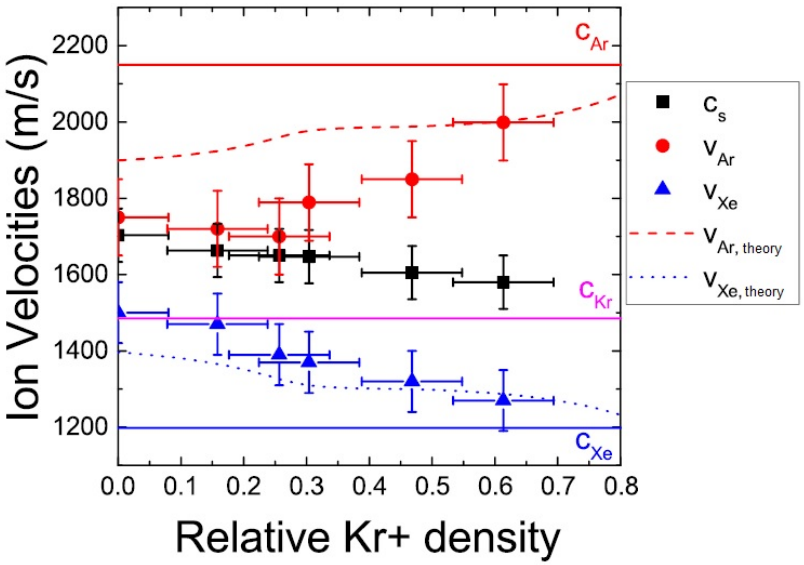

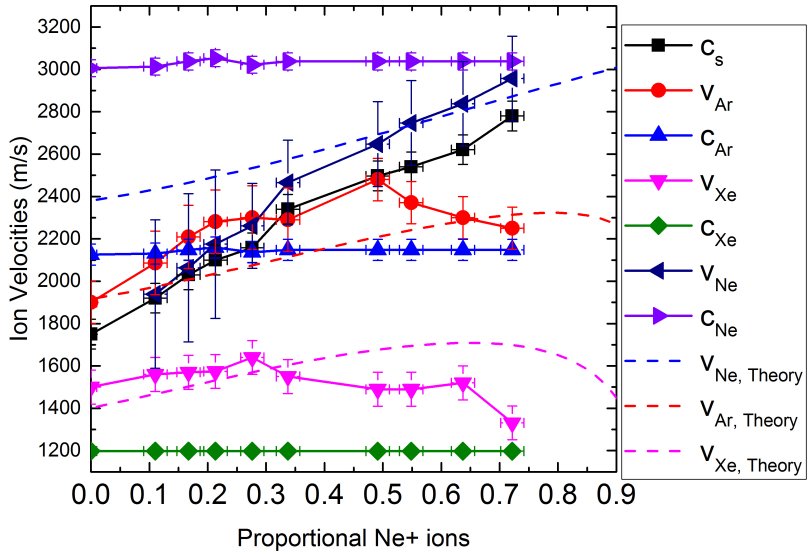

THESE RESULTS ARE NOT SIMPLE....but thanks for your attention anyway!:)