MULTI-ELEMENT STARK BROADENING FOR DIAGNOSING ELECTRON DENSITY IN HED PLASMAS

SAND2018-7521C

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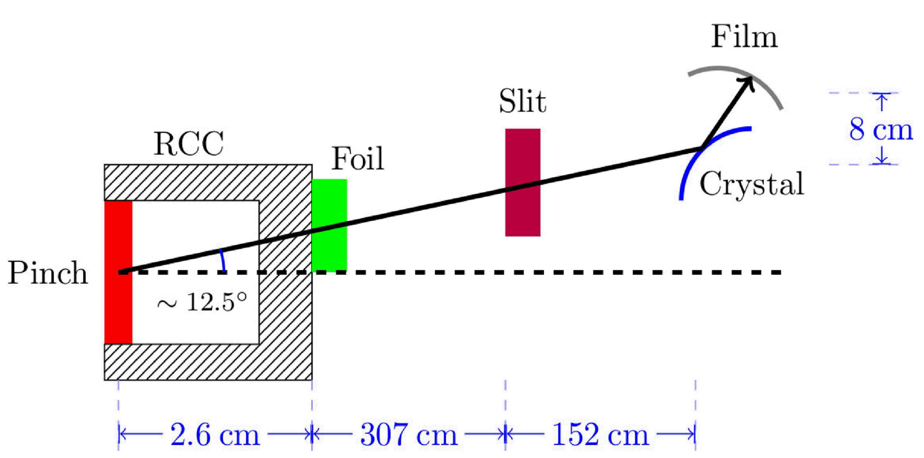
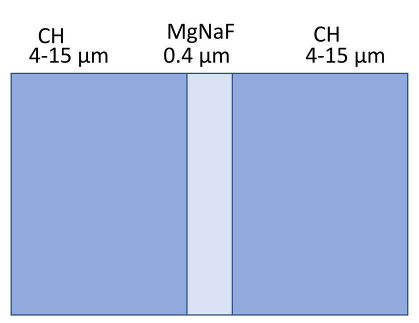
Abstract

The interpretation of spectral line shapes for plasma characterization is well established as a diagnostic technique for determining number density and electron temperature, essential parameters for predicting radiation dynamics, local thermodynamic equilibrium, and atomic kinetics in laboratory and astrophysical environments. Specifically, Stark broadening is often used to diagnose a plasma's electron density via a tracer element. We are interested in testing whether Stark broadening models can predict the plasma density from multiple elements within the same plasma, and whether this is done self-consistently. In order to do so, we diagnose transmission spectra through ~0.4-um-thick Mg-NaF foil on Sandia's Z facility. This foil is tamped with varying amounts of CH, allowing for electron densities between 1x10^{21} and 1x10^{22} cm^{-3} to be reached. The foil is heated such that He-like charge states were reached for all three elements, allowing for investigation of Stark broadening of those lines. The amount of broadening found from different elements, and different tamper thicknesses will be discussed further.

Z facility provides excellent test bed for multi-element stark broadening



- The Z Pinch Dynamic Hohlraum (ZPDH) generates 1.6 MJ of x-ray energy. These x-rays both heat and backlight a Mg-NaF foil.
- The spectra is then incident on the cylindrically bent KAP crystal in the TIXTL.
- The crystal diffracts different wavelengths to positions on the x-ray film, providing spectral resolution.

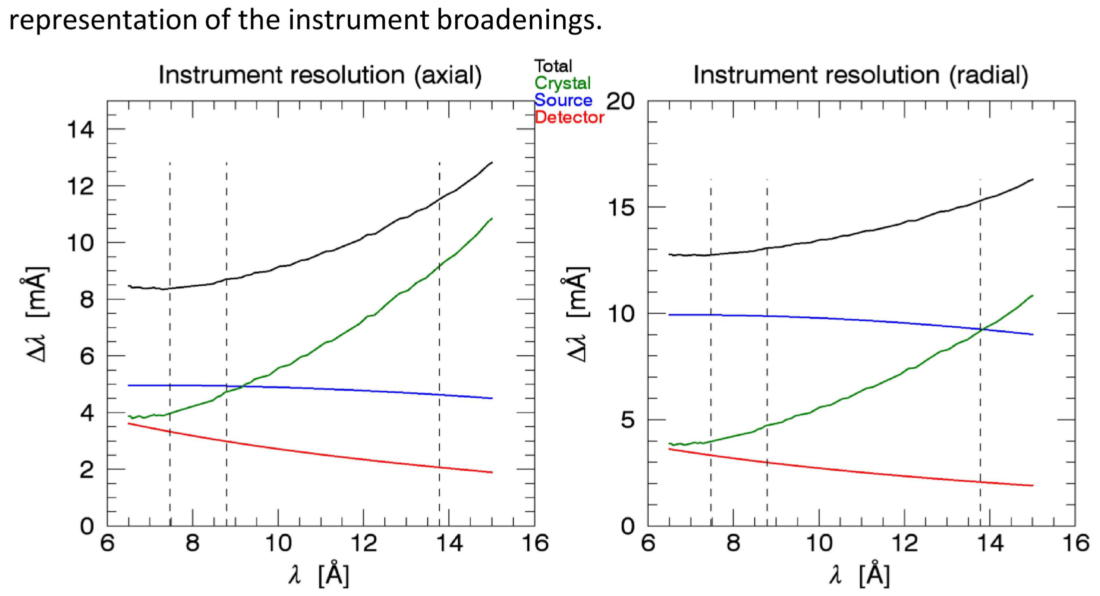


- The foil is comprised of Mg-NaF, made of 20 alternating layers of NaF and Mg sandwiched between two CH tampers.
- The CH tampers are varied in thickness from 4 to 15 µm, allowing for different densities.

In order to resolve Stark broadening, instrument broadening must be known

Source of broadening	Distribution Function	Average $\lambda/_{\Delta\lambda}$	$\Delta\lambda$ [mÅ] at 11Å
Source Size	Based on Spatial distribution	2000	5.5
Rocking Curve	Lorentzian	1700	6.47
Detector (Film)	Gaussian	4000	2.75

- These sources of broadening are due to the geometry of our experimental setup, and therefore are not affected by varying plasma parameters. Below is graphical representation of the instrument broadenings.



It is important to take into account broadenings in the plasma as well, such as Doppler broadening and Intrinsic line width

$$\frac{\Delta\lambda}{\lambda} = 2\sqrt{\frac{2T\log 2}{Mc^2}}$$

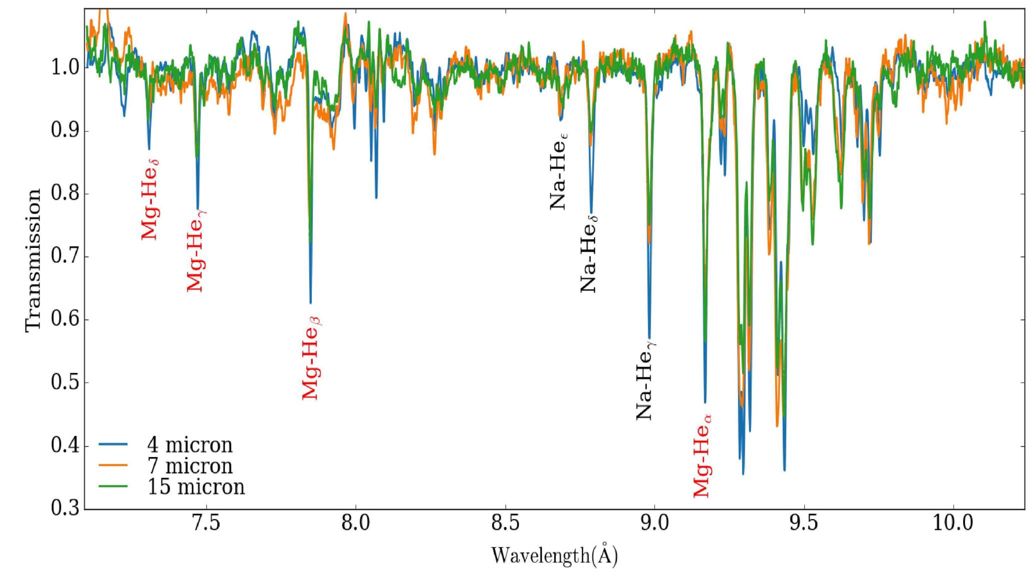
- Plasma temperature and species mass can be used to determine random thermal motions effect on lines within the spectra, known as Doppler broadening (Salzman, 2009).

	F	Na	Mg
$\lambda/_{\Delta\lambda}$	6700	7400	7600

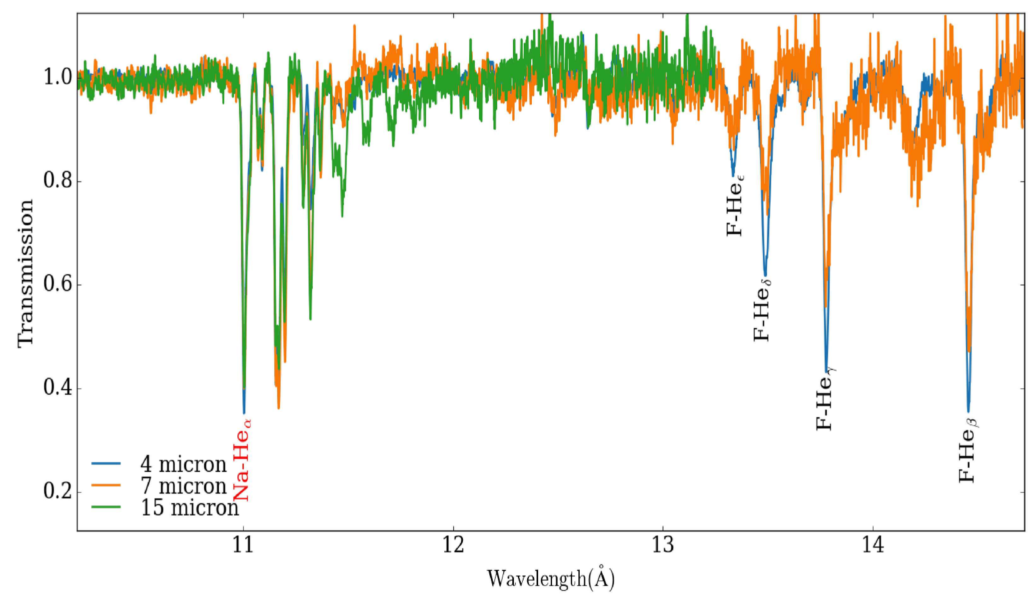
- Intrinsic line width derives from the Heisenberg Uncertainty equation. Therefore it is generally very small. A nominal value for our ΔE is ~ 0.0007 eV, or a $\lambda/_{\Delta\lambda}$ of ~1.5*10^6

$$\Delta E = \frac{\hbar}{2} A_{ij}$$

Spectra from all three tamper thicknesses show a multitude of lines, including He-like charge states.



- He-like lines are observed for both Mg and Na for all three tamper cases.

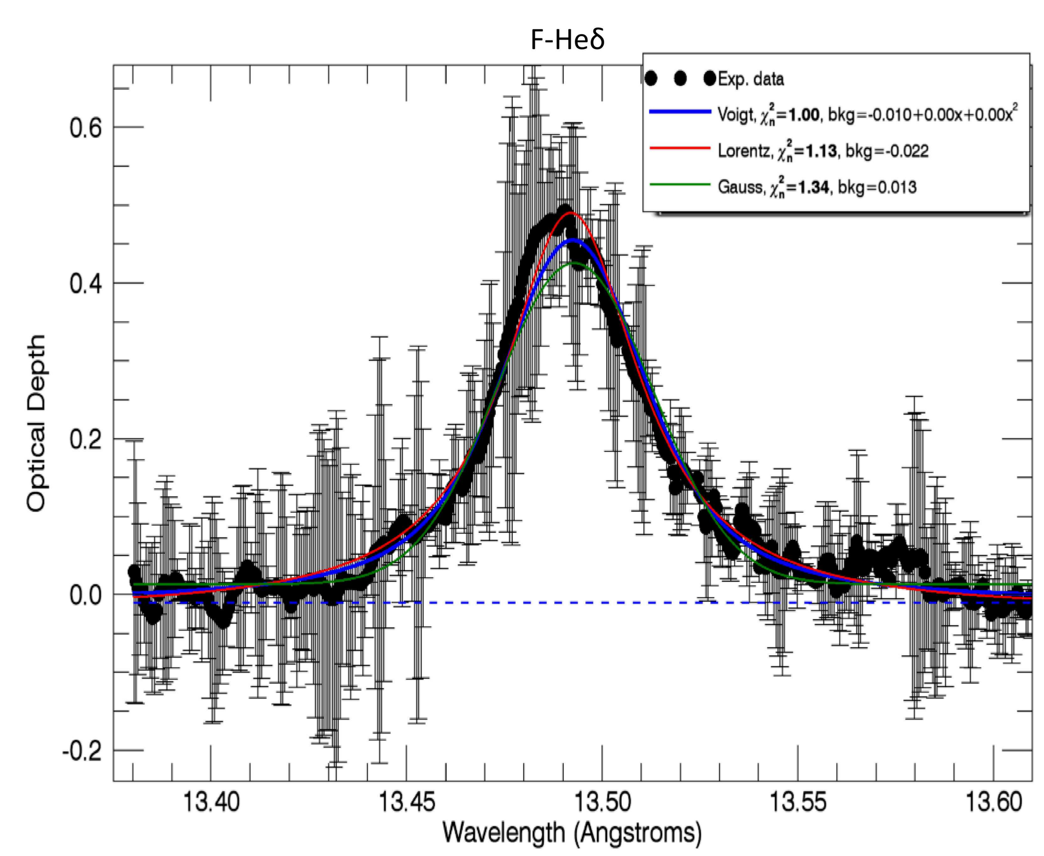


- He-like F is not seen in the 15 micron tamper case, since CH attenuates more at these wavelengths.

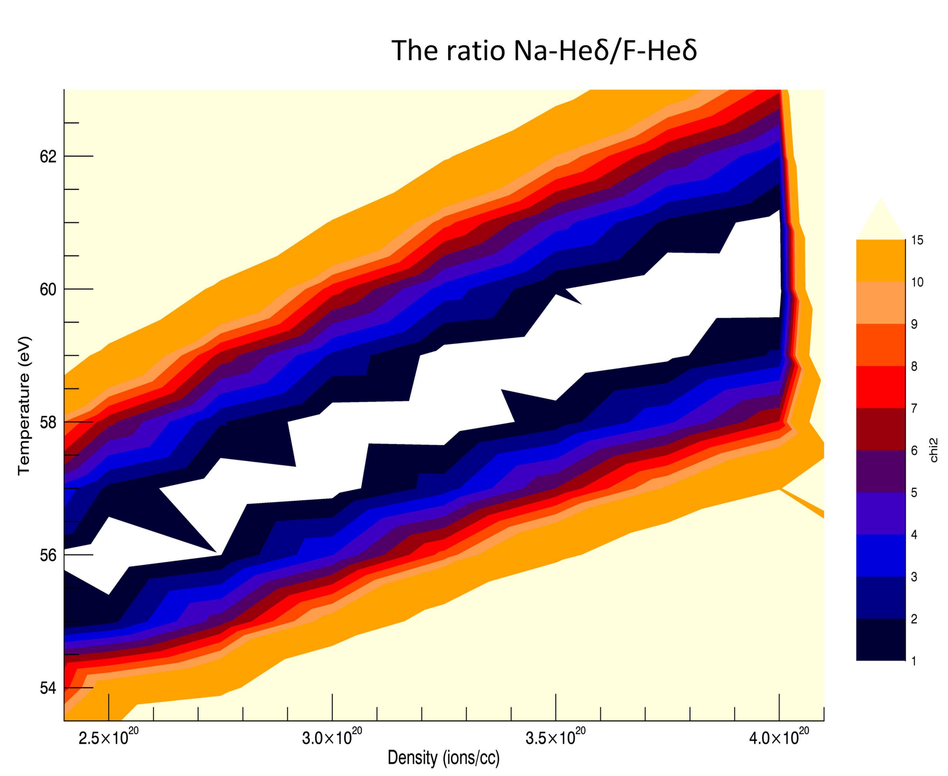
Converting transmission into optical depth allows for more accurate line fitting.

$$T_L = e^{-\tau}$$

- Using the Beer-Lambert Law, the spectra can be converted to optical depth (τ) and fit with Voigt, Lorentzian and Gaussian profiles.
- The values from the Voigt profile will be used from here on.

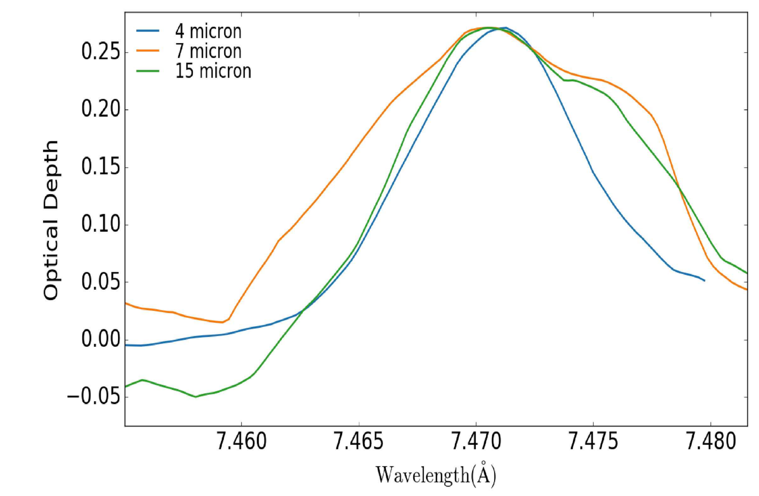


A Chi-squared analysis of line ratios provides a confidence interval for determining the temperature of the plasma

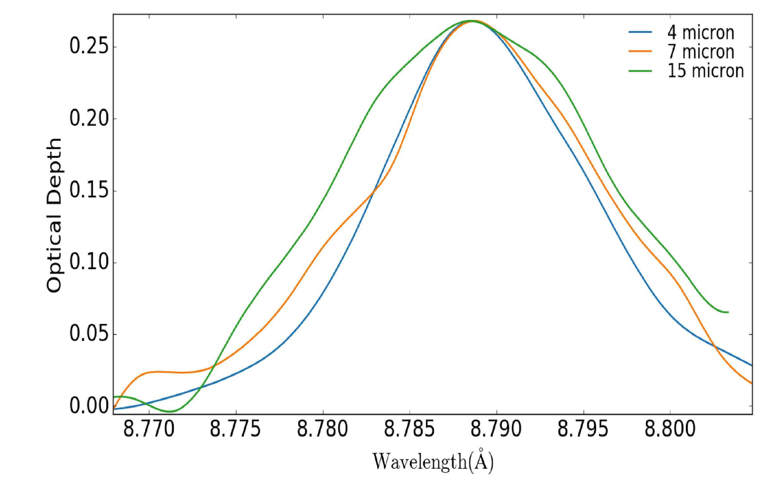


- A fitting and analysis algorithm was developed at WVU called HADHES, which allows for simulated line ratios to be calculated efficiently from PrismSPECT simulated spectra.
- Using the ratio values and errors found from the experimental data, we can create a chi-squared map in temperature-density space, giving us estimates of the temperature and density.

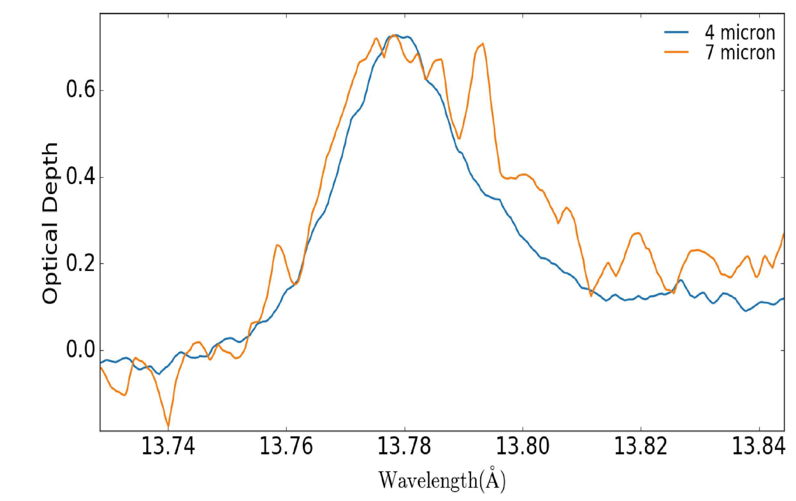
A normalized signal shows apparent stark broadening



- The Mg-Hey appears to be broadening as tamper thickness is increased, but after a more in depth analysis, this is largely due to the instruments maximum resolution (values provided in the table below). This could be fixed by using the second order reflection from the KAP crystal.



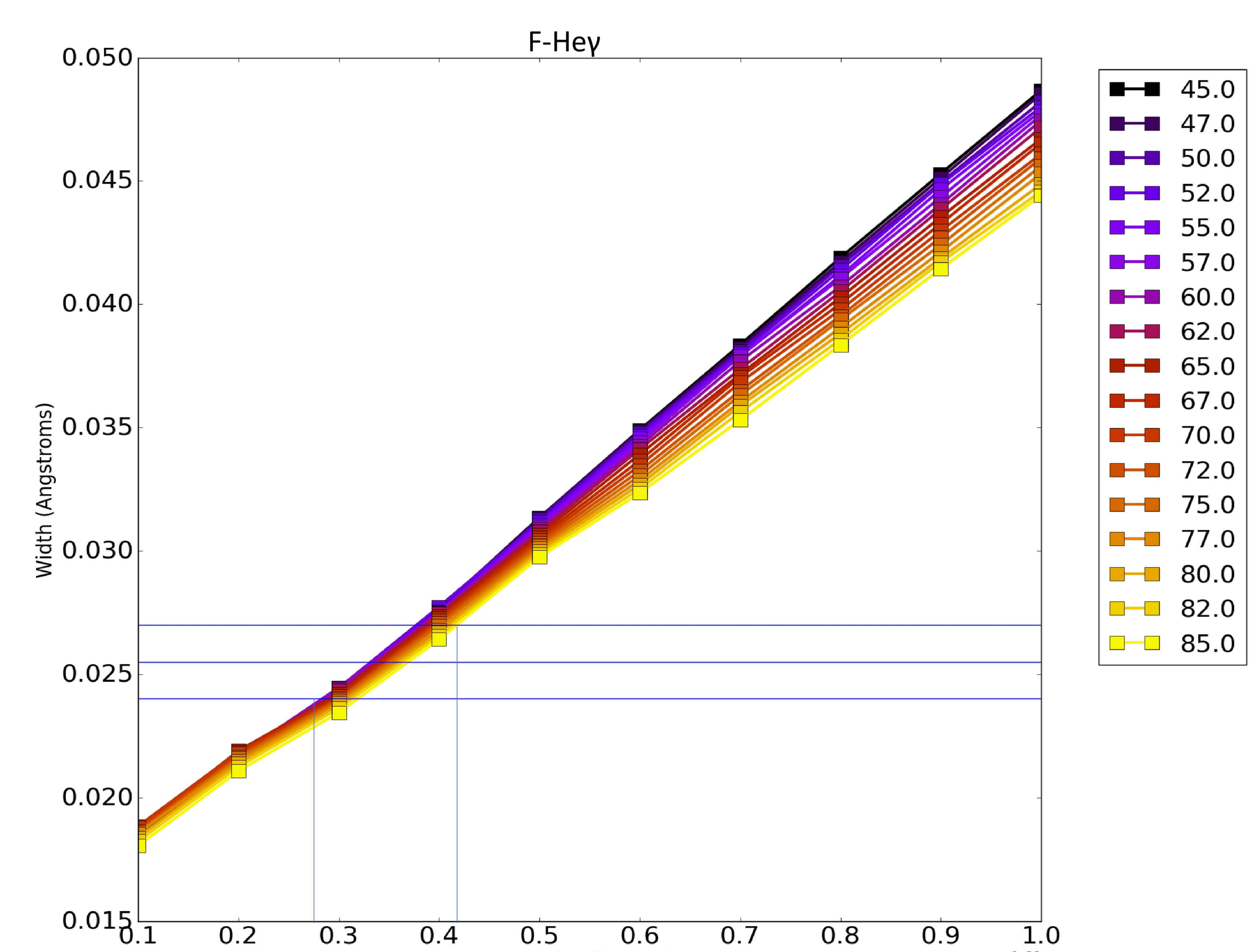
- However, the Na-Heδ has widths above the instrument resolution for all tamper thicknesses. Therefore, the observed broadening is most likely due to Stark effects.



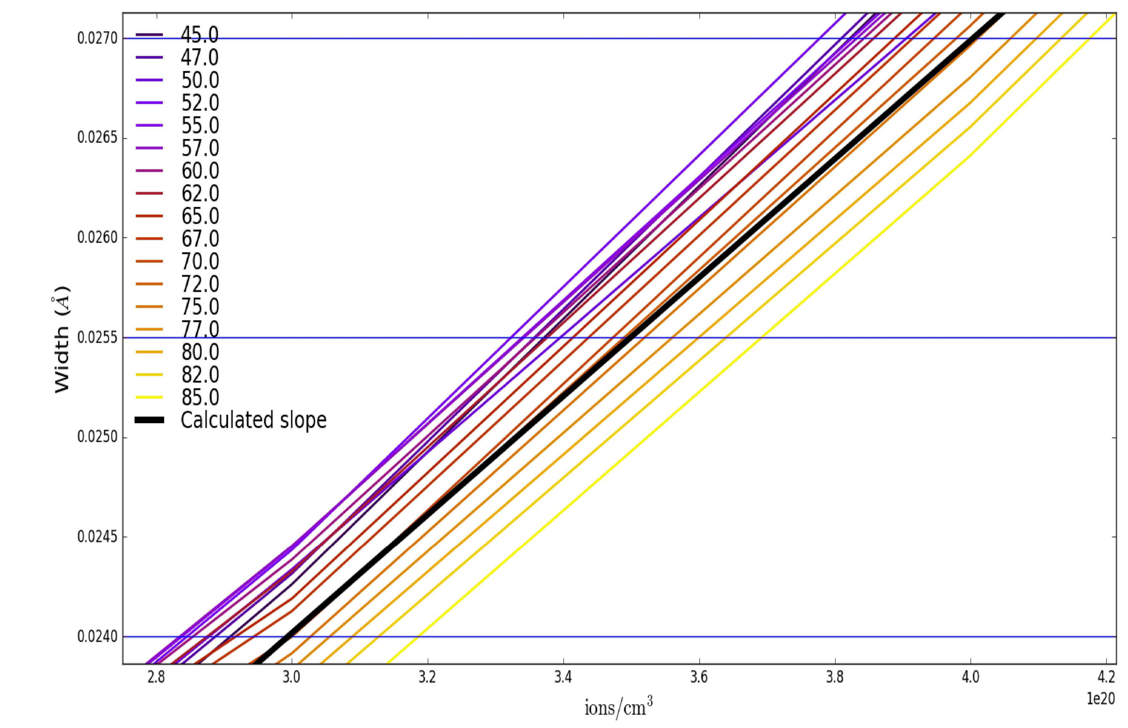
- Similarly, the F-Hey starts well above the instrument broadening and only grows. Unfortunately, the thickest tamper did not provide F lines.

Line	Tamping [µm]	Orientation	Voigt Width [mÅ]	Error in width [mÅ]
Mg-Hey	4	Axial	8.7	0.21
Mg-Hey	7	Radial	13.1	0.0959
Mg-Hey	15	A&R	13.2	0.138
Na-Heδ	4	Axial	13.9	0.17
Na-Heδ	7	Radial	14.3	0.08
Na-Heδ	15	A&R	17.7	0.36
F-Hey	4	Axial	25.5	0.15
F-Hey	7	Radial	27.2	0.463

The predicted widths of He-like lines can be fit across a range of temperatures and densities, allowing for a comparison with the data.



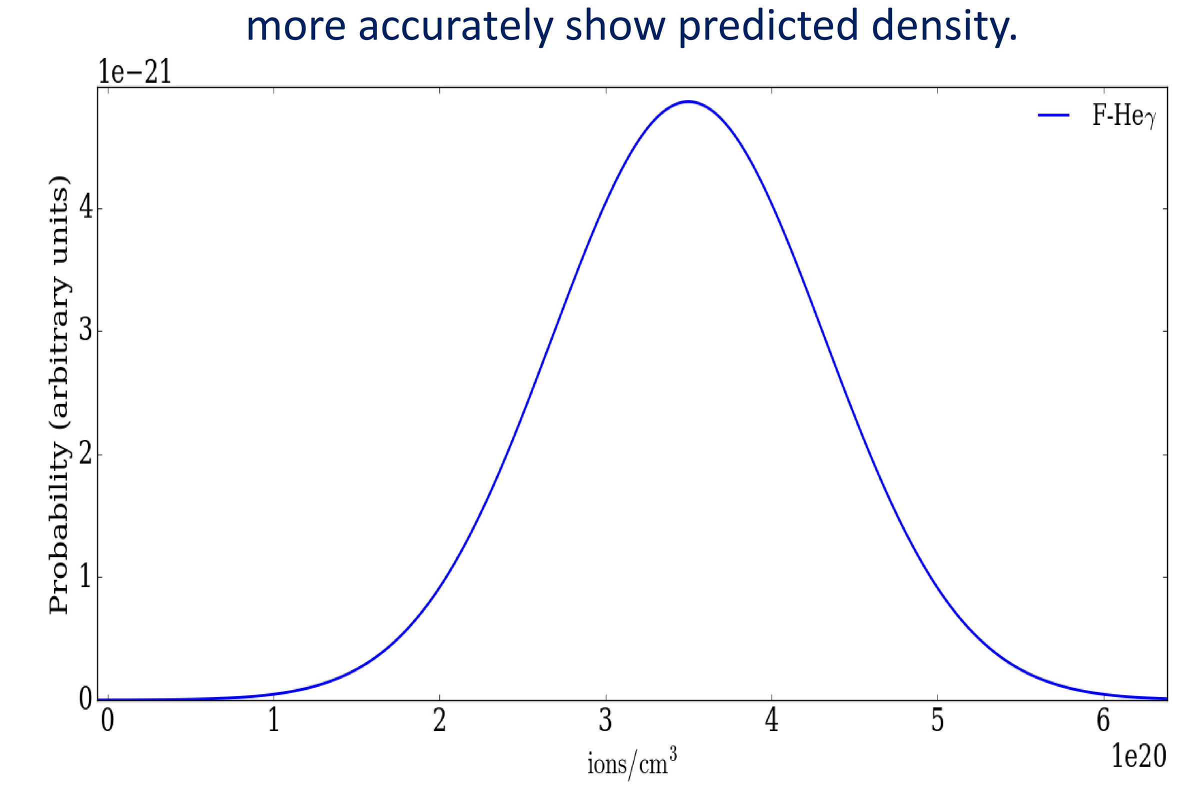
By fitting the observed trends with a line, the link between width and density becomes more obvious.



Width = m*density + b

- A linear equation relates a line's width and the plasma's density.
- The slope of the line can be varied to indicate a gradient within the plasma
- The y-intercept can vary based on the temperature of the plasma
- This calculated line used an average of the different temperatures, with the spread in values taken as the error

Assuming a Gaussian distribution for the error in the density, the linear relation between width and density can be used to more accurately show predicted density.



- Since a Gaussian error distribution is assumed, the linear transformation yields another Gaussian. This can be used moving forward to determine agreement between predicted densities from different lines. This can be shown by whether or not all the predicted values fall within 2σ of each other, showing a 95% agreeance.

Conclusions/Future Work

- We have a platform that is poised to measure Stark broadening effects on He-like lines across two different elements, with a third coming soon.
- Our next shot series will be using an axially resolving spectrometer. All three tamper thicknesses will be measured.
- Second order reflection of KAP crystals is an option for helping resolve broadening in He-like Mg lines. This may be used in our next shot series as well
- Once experiments are completed, line widths found in experiment will be compared to those produced by various codes to see if they can replicate a singular density using three elements.

Acknowledgements

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists, Office of Science Graduate Student Research (SCGSR) program. The SCGSR program is administered by the Oak Ridge Institute for Science and Education (ORISE) for the DOE. ORISE is managed by ORAU under contract number DE-AC05-06OR23100.
This material is also based upon work supported by the U.S. Department of Energy, Office of Science under contract number DE-SC0012515
Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

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