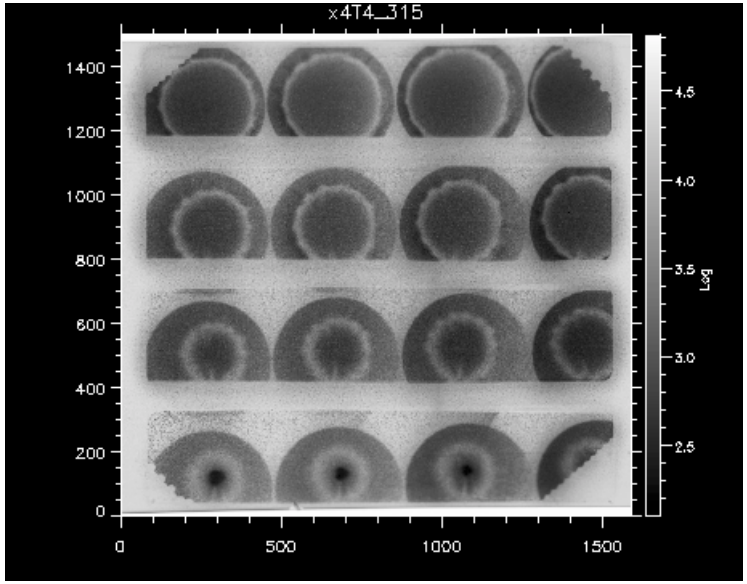
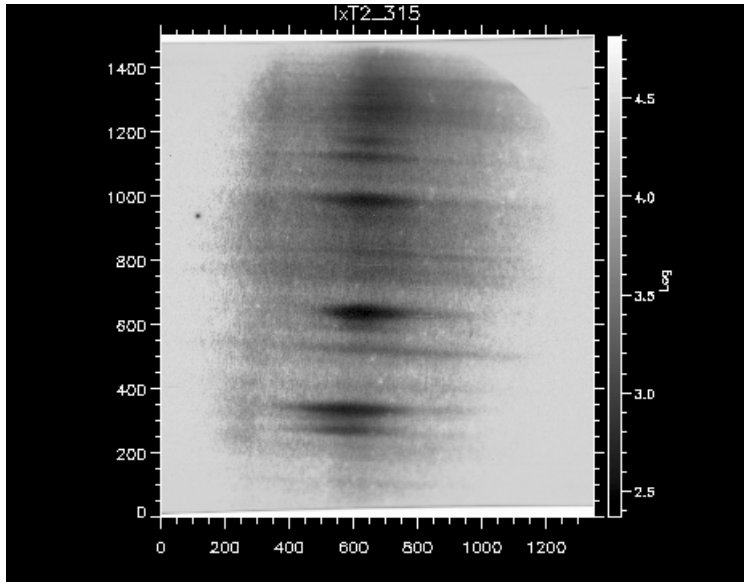
X-ray Spectroscopy of Directly Driven Cylindrical Implosions





Presented at the
LANL Cylindrical Implosion Program Review
Don Haynes
Fusion Technology Institute
University of Wisconsin
9/29/99

UNIVERSITY OF WISCONSIN MADISON
150 YEARS

Collaborators

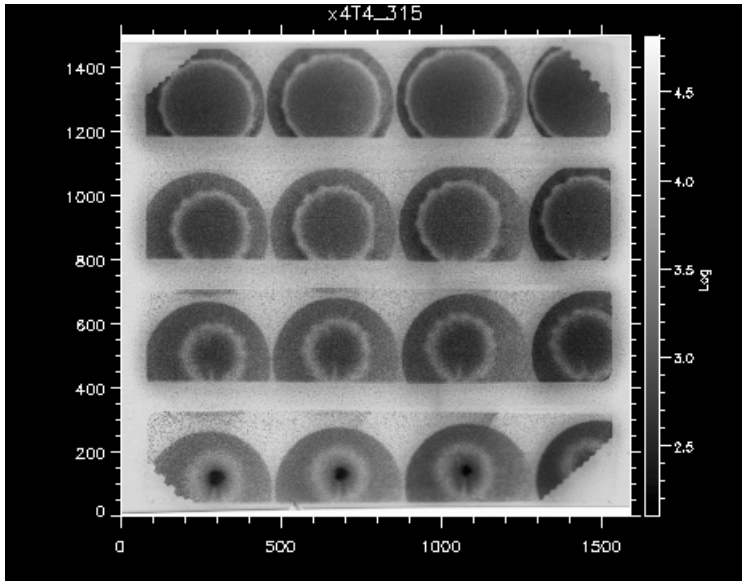
- UF: C. F. Hooper, Jr.
- LANL: N. Delamater, C. Barnes, G. Pollak
- LLE: P. Jaanimagi

Outline

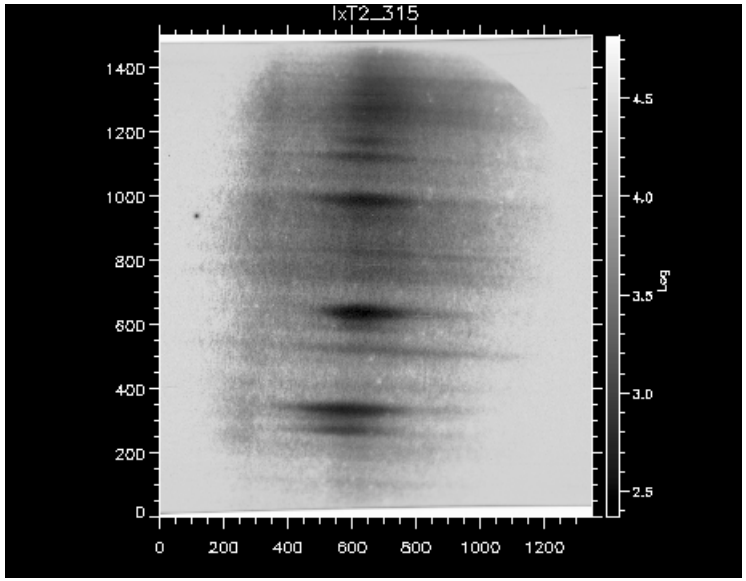
- Why were these experiments performed?
  - Given that, why do spectroscopy?
- Experimental details
  - Targets, spectrograph
- Spectral Data
  - Cl K-shell emission recorded using LXS
- Analysis
  - Review of venerable “Line of Best Fit” analysis, (giving credit where credit is due)
  - Application of LIBEF to this data
- Discussion of hydrodynamic simulations and interpretation of analysis
- Summary/Conclusions

Why were these experiments performed?

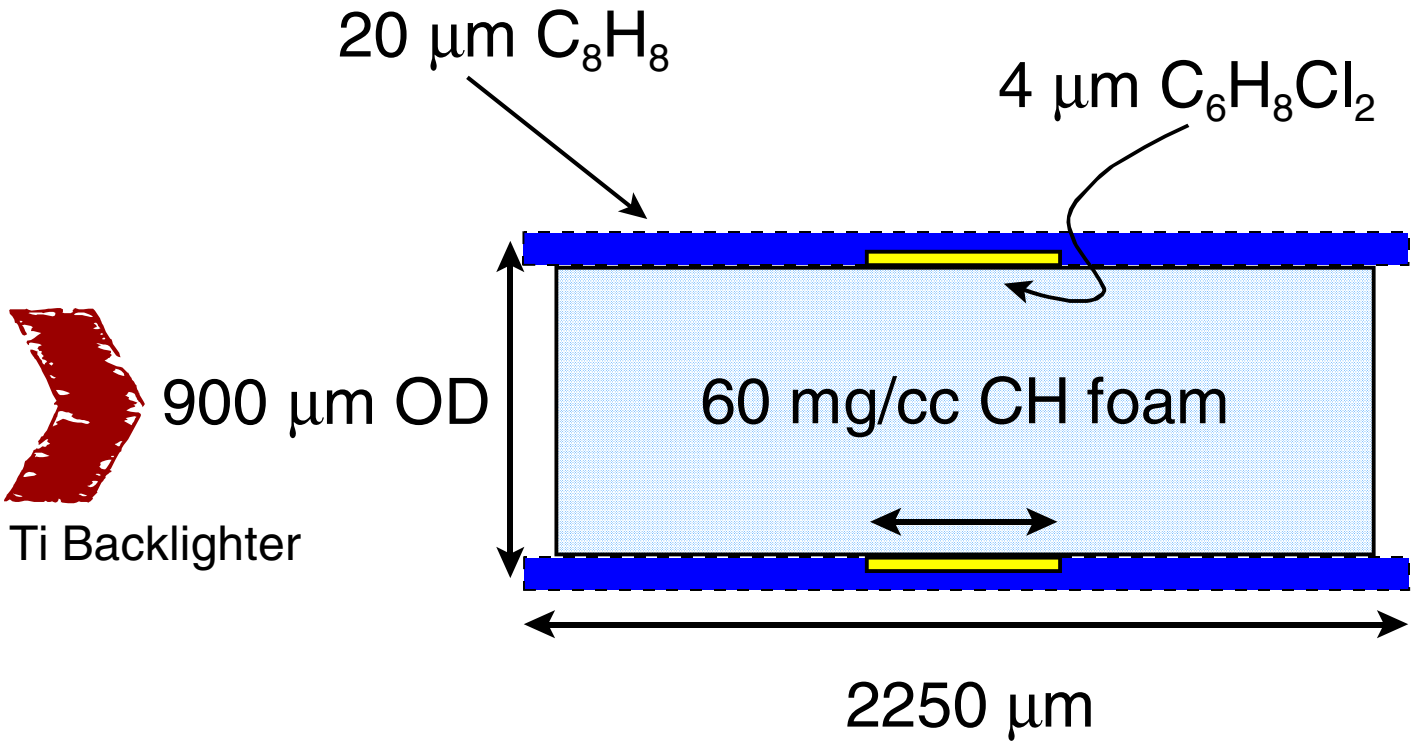
- **Primary Goal**:
  Study R-T growth in a converging geometry with excellent diagnostic access.

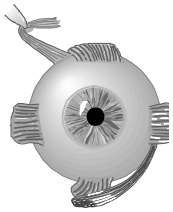


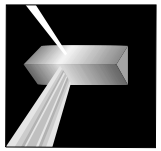
- **Tertiary Goal**:
  Investigate the practicality of using this geometry for line broadening studies in dense plasmas.



Experimental Details: Targets





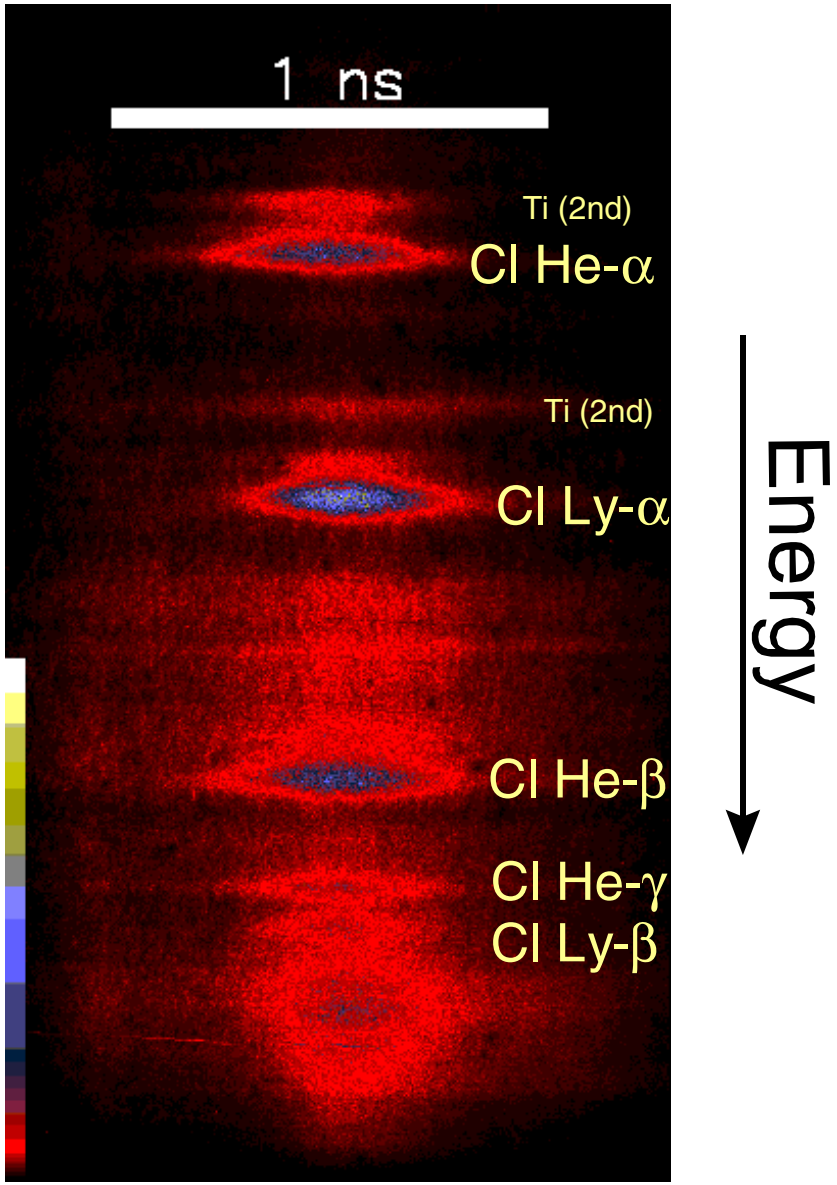


Experimental Details: Spectrograph

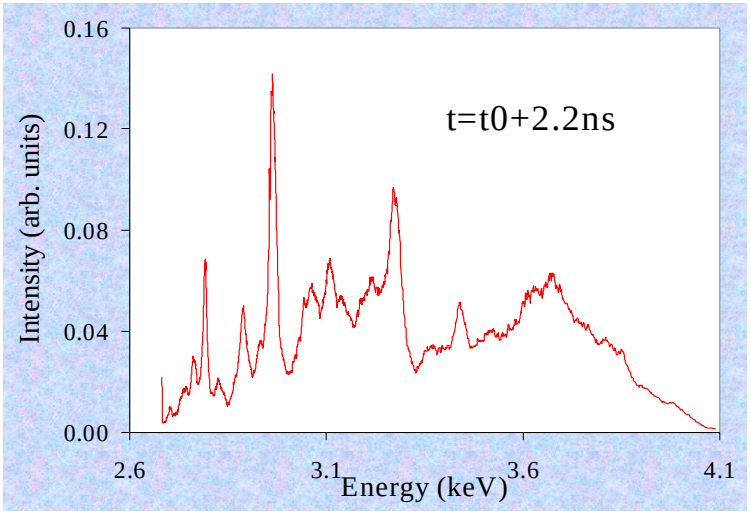
- LLE X-Ray Streak Camera
  - **Advantages**:
    - Vertical slit spectrograph: source size broadening determined by diameter, not length
    - Curved crystal: source size demagnification of 2.5
  - **Challenges**:
    - Inexperience
    - No fiducial trace on July 1998 shots
    - Barrel distortion from curved screen
    - Non-linear dispersion relationship
  - **Characteristics**:
    - 125 micron resolution: $E/\Delta E \sim 500$ at Cl He-α
    - 10 ps temporal resolution (though not nearly enough photons to take advantage of this)

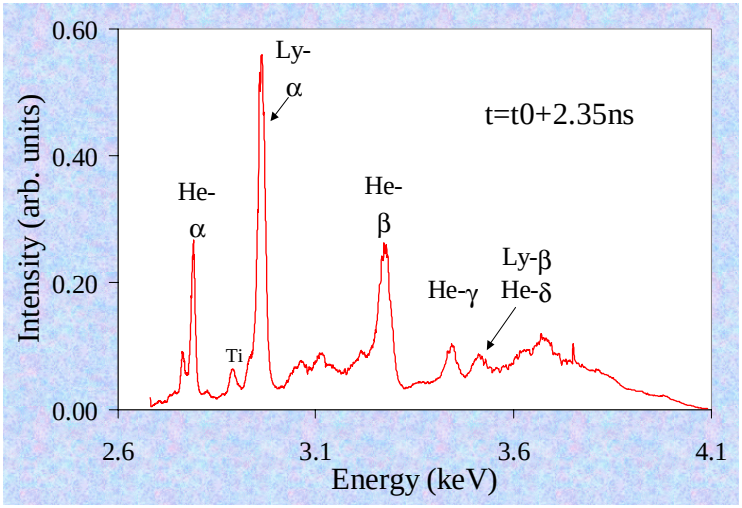
Typical spectral data. Really.

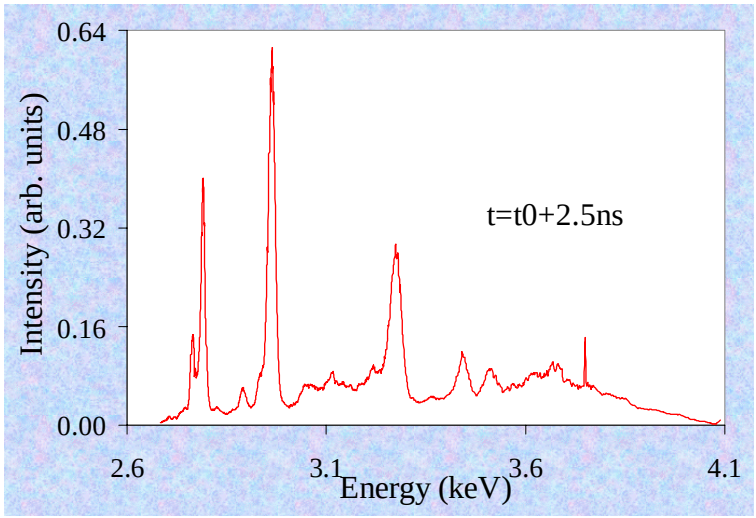
- Data Reduction:
  - Film density to exposure conversion
  - Streak angle
  - Barrel distortion
  - Dispersion
  - Sweep speed, absolute timing wrt laser pulse from IXRSC
- Result:
  - Time-resolved (averaging over 160ps) **lineouts** of Intensity (arb units) vs. Energy (eV)

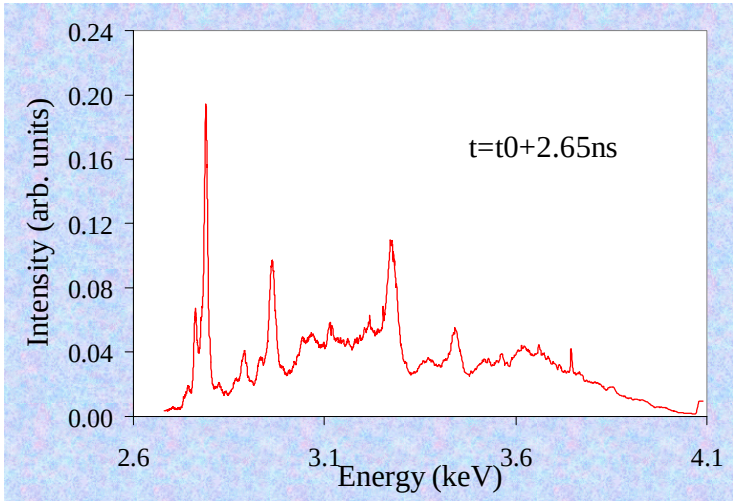


Time-resolved lineouts







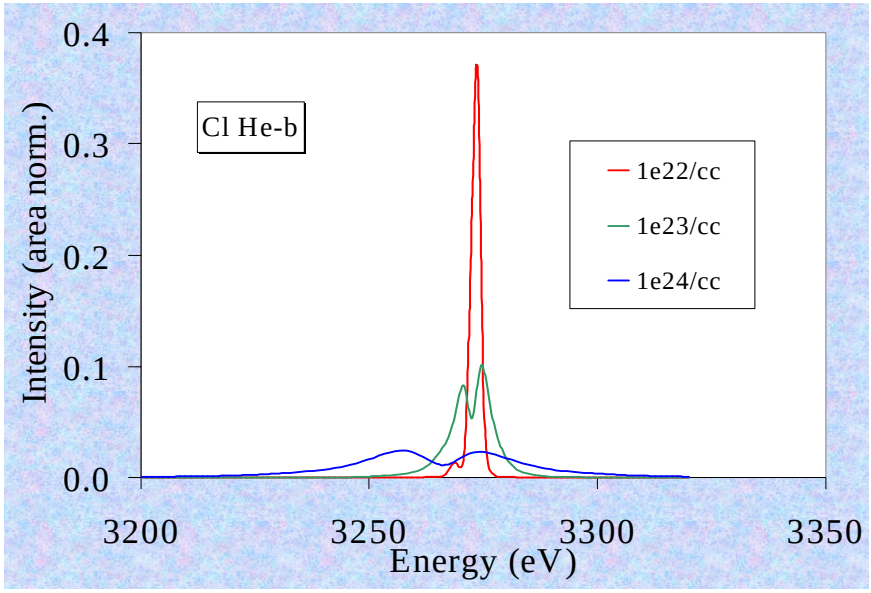


Analysis: “Line of Best Fit”

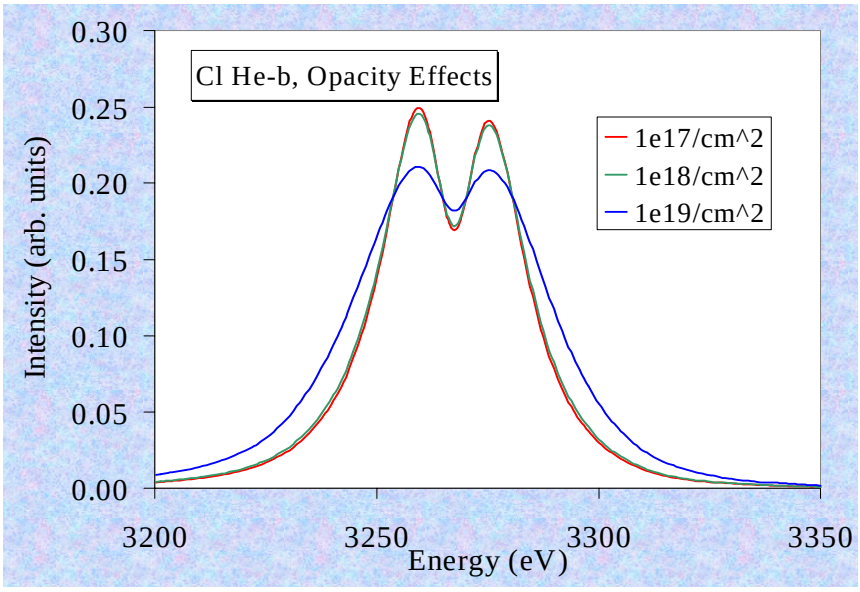
- Absent a model of the plasma which relates optical depth to electron density, a given line’s width (and often, practically speaking, even its shape) does not uniquely determine the electron density of the plasma.
- For these marker layer plasmas, the line shapes are determined by:
  - Stark broadening, and
  - Opacity effects
- Given the lack of a reliable model which explains the observed emission, we turn to the method of Kilkenney, Lee, Key and Lunney (PRA **22** 2746 (1980)), examining multiple lines with a common set of lower levels.

The Stark effect and opacity each can broaden lines, but affect different members of a Rydberg series differently.

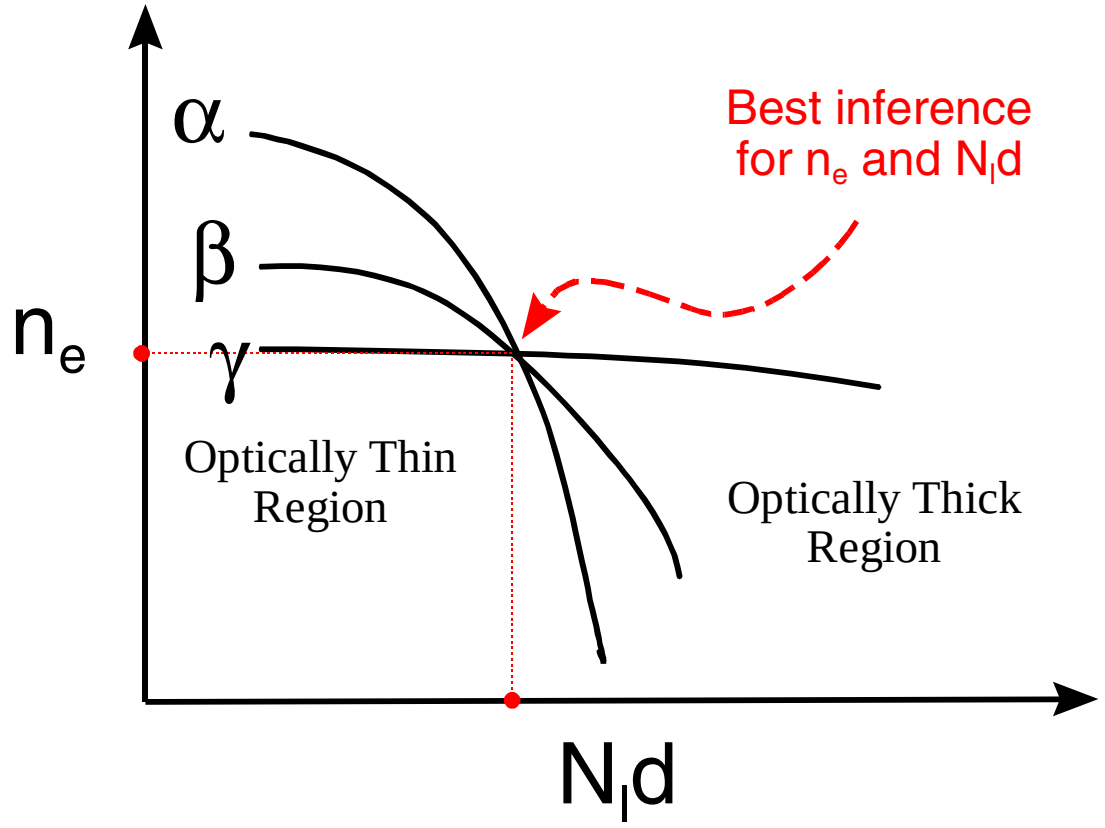
Stark Broadening



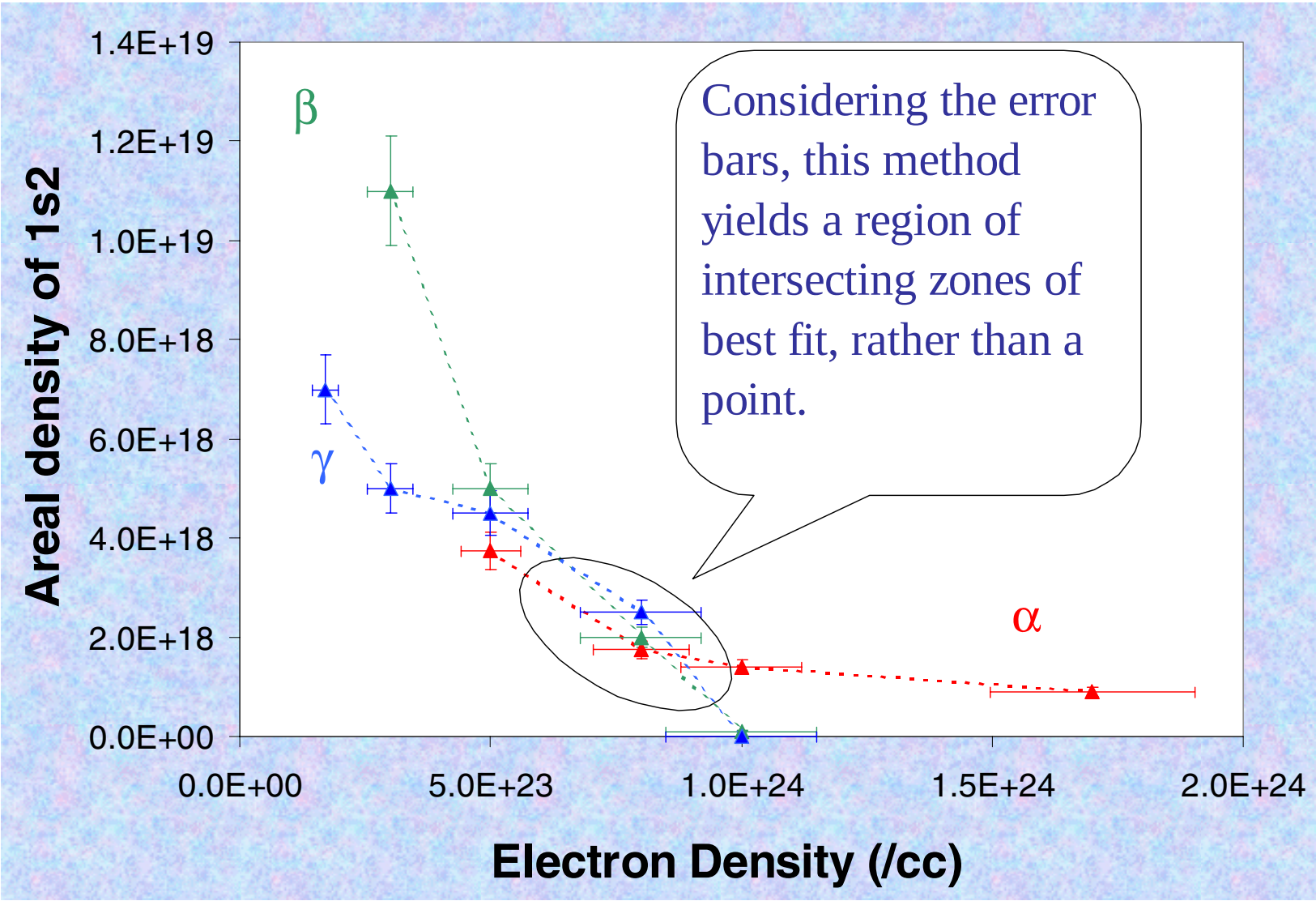
Opacity Effects



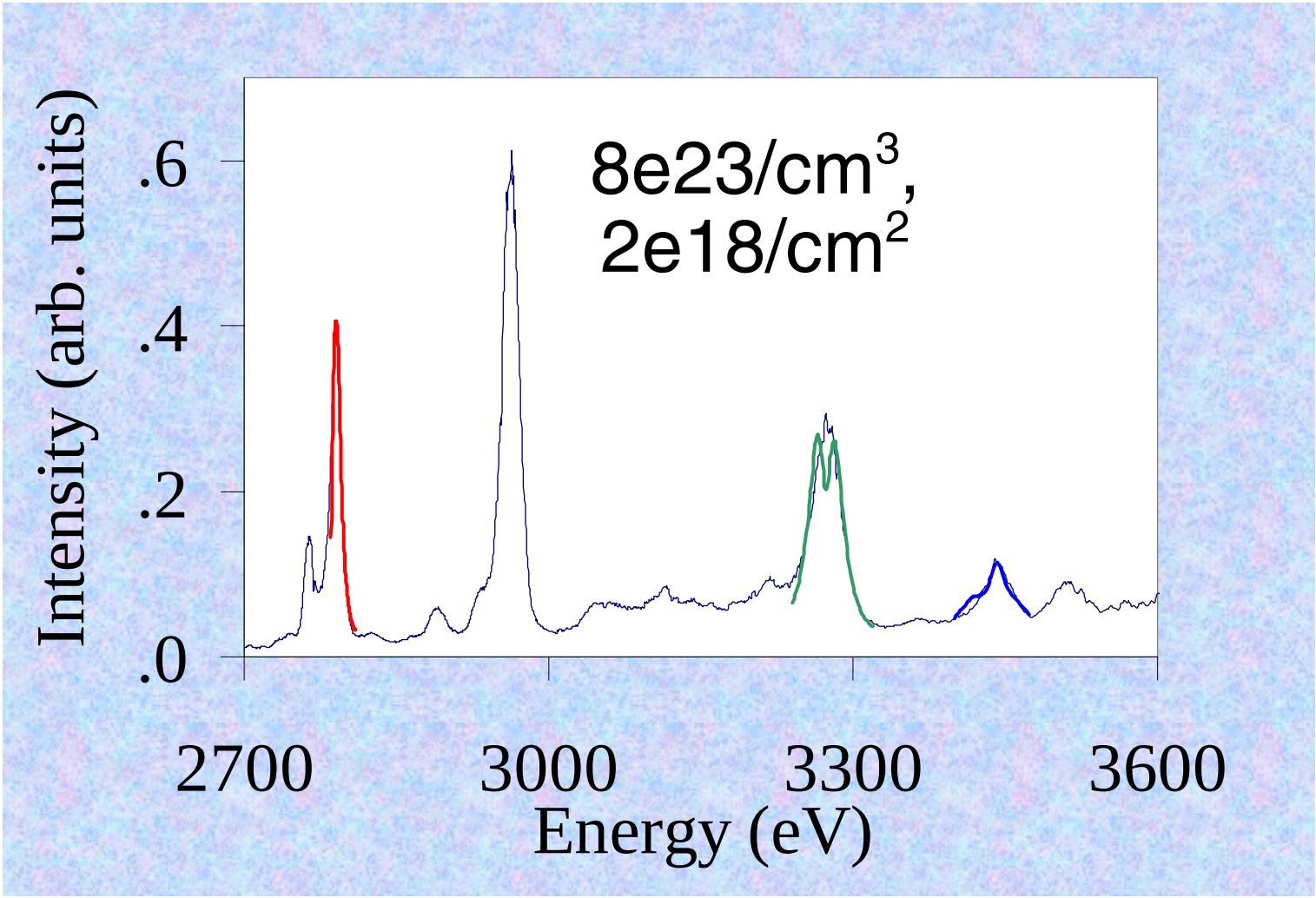
In Kilkenney, *et al.* (PRA 1980) the authors fit multiple lines from a Rydberg series, effectively plotting the loci of best fits in the n_e-$N_l d$. The overlap of these loci provided an inference of **both** electron density and optical depth.



Analysis: LIBEF applied

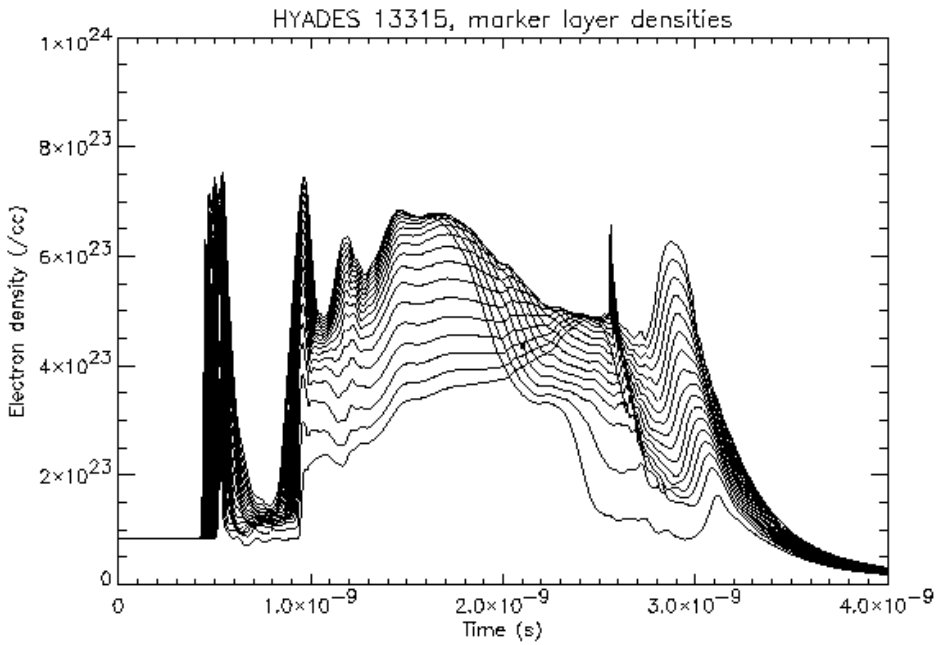


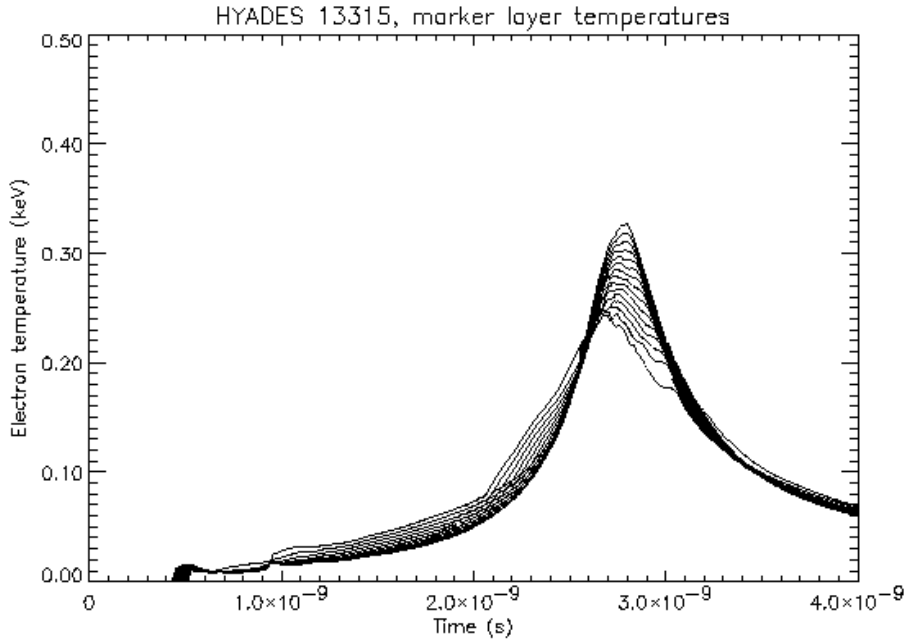
Analysis: LIBEF applied



1- and 2-d simulations, when post-processed with TDG, do not predict emission of Cl K-shell lines!

HYADES simulations were performed by C. Barnes and N. Shambo to aid in target and pulse design, and I can show those.





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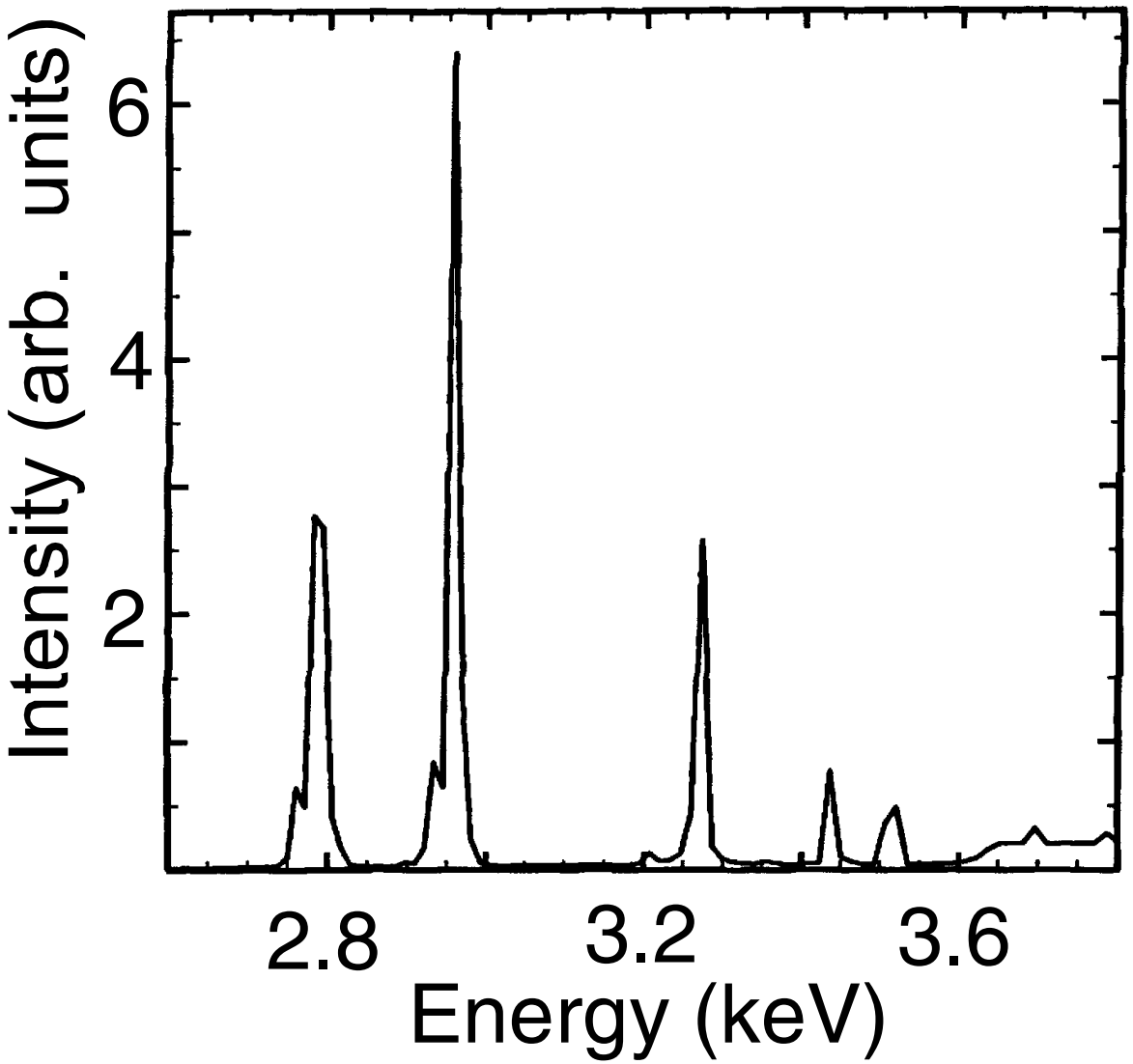
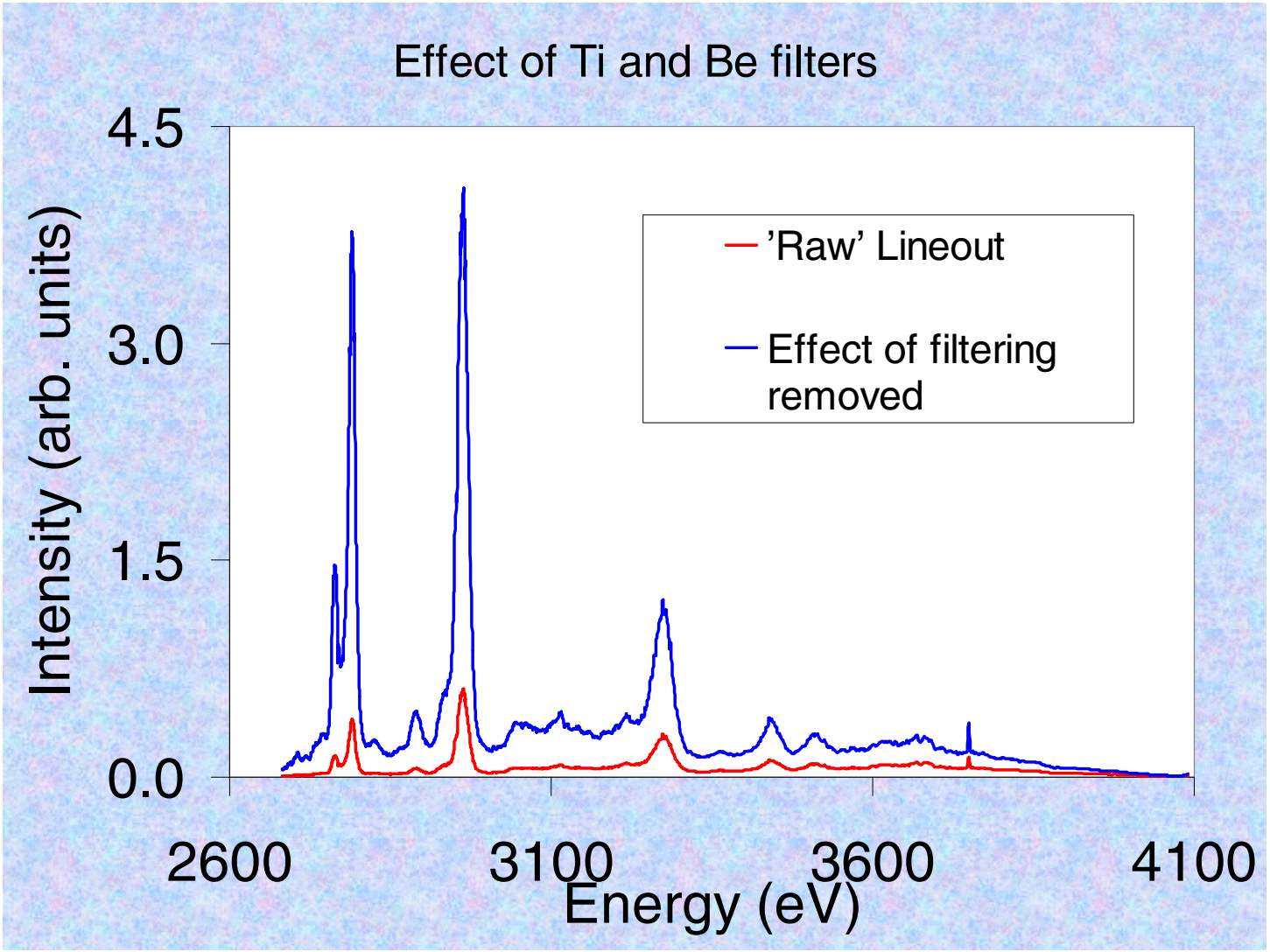
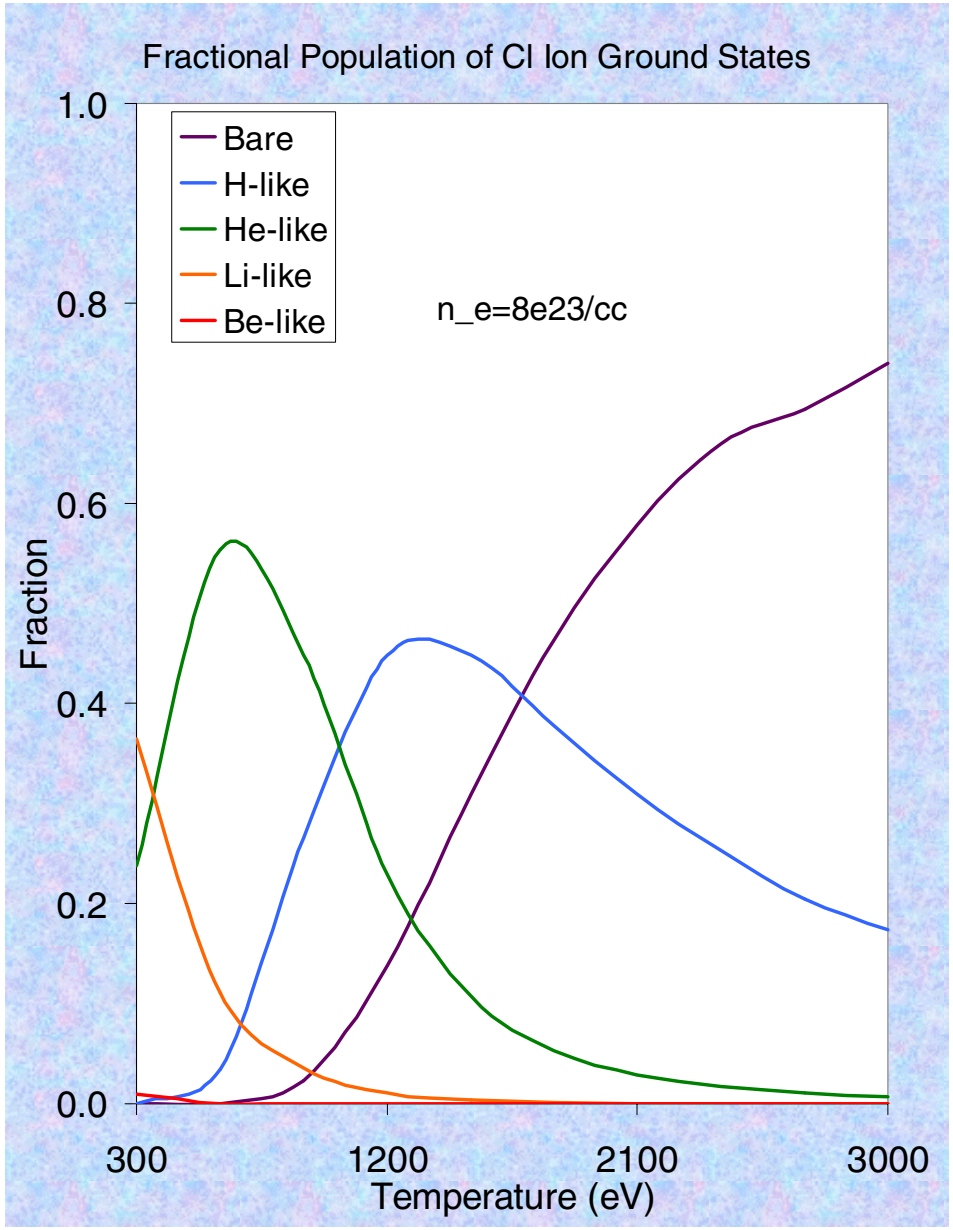


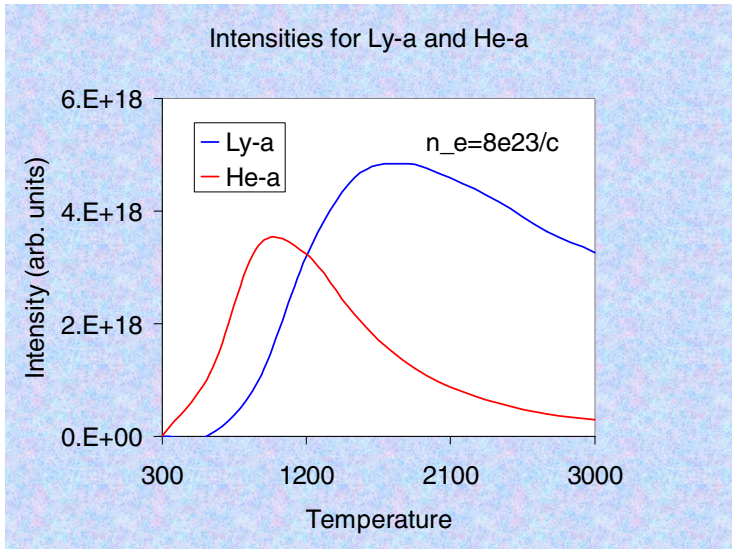
- If the laser pulse is arbitrarily extended, then the Cl lines are simulated to emit, though at times ruled out by experiment.
- If the Cl marker layer is arbitrarily allowed to diffuse through the target, the Cl lines can be forced to emit at the time seen in the experiment.

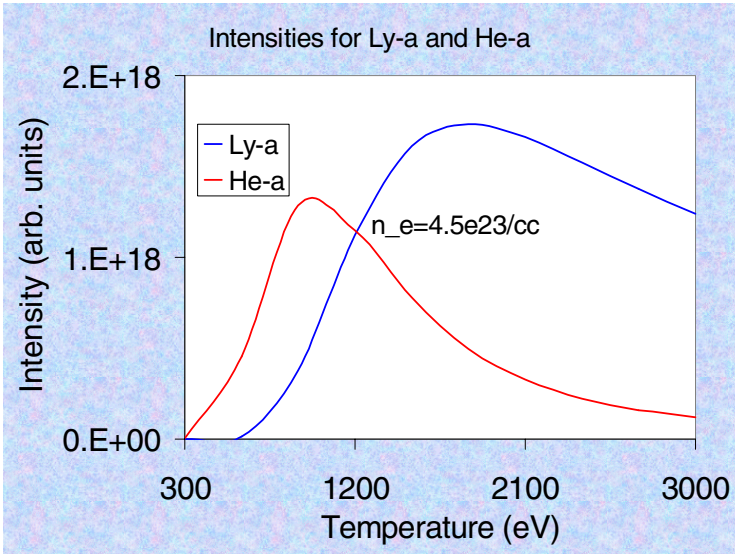
Effects of Ti and Be filtering need to be considered before temperature inference is attempted



Constraints on marker layer temperature







Analysis of the Cl spectra indicate that the Cl lines are emitted from a region with electron density near that of the solid marker layer.

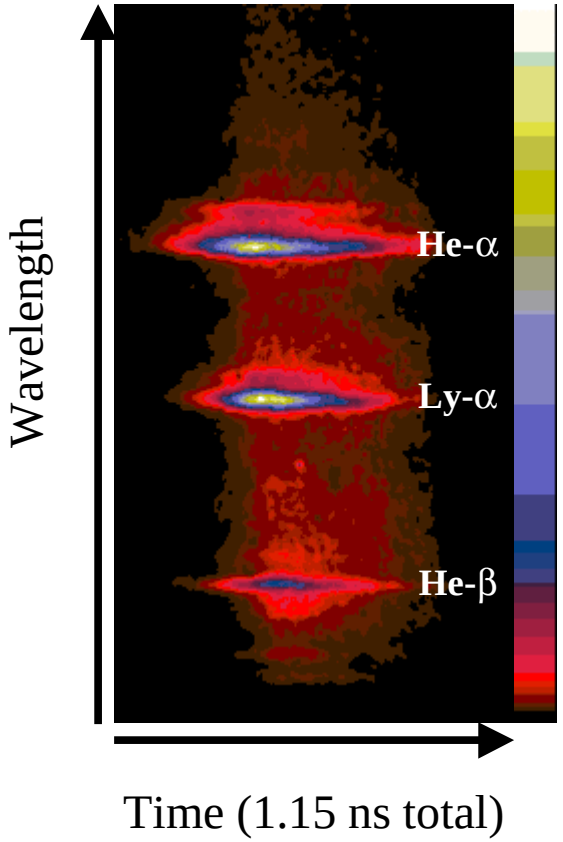
- Three possibilities come to mind, which are currently under investigation:
  - ~~The process of leeching out the mandrel may cause the Cl marker layer to "migrate".~~
  - Systematic underestimation of the CH thickness.
  - The laser-speckle imprinting in these direct drive implosions may be causing RT simulated mix not included in the hydrodynamic simulations. This "Delettrez Effect" (Delettrez, *et al.* Phys. Plasmas **1**) has been extensively studied at LLE in planar and spherical geometries.

Doping the foam with Cl permits study of the evolution of core conditions

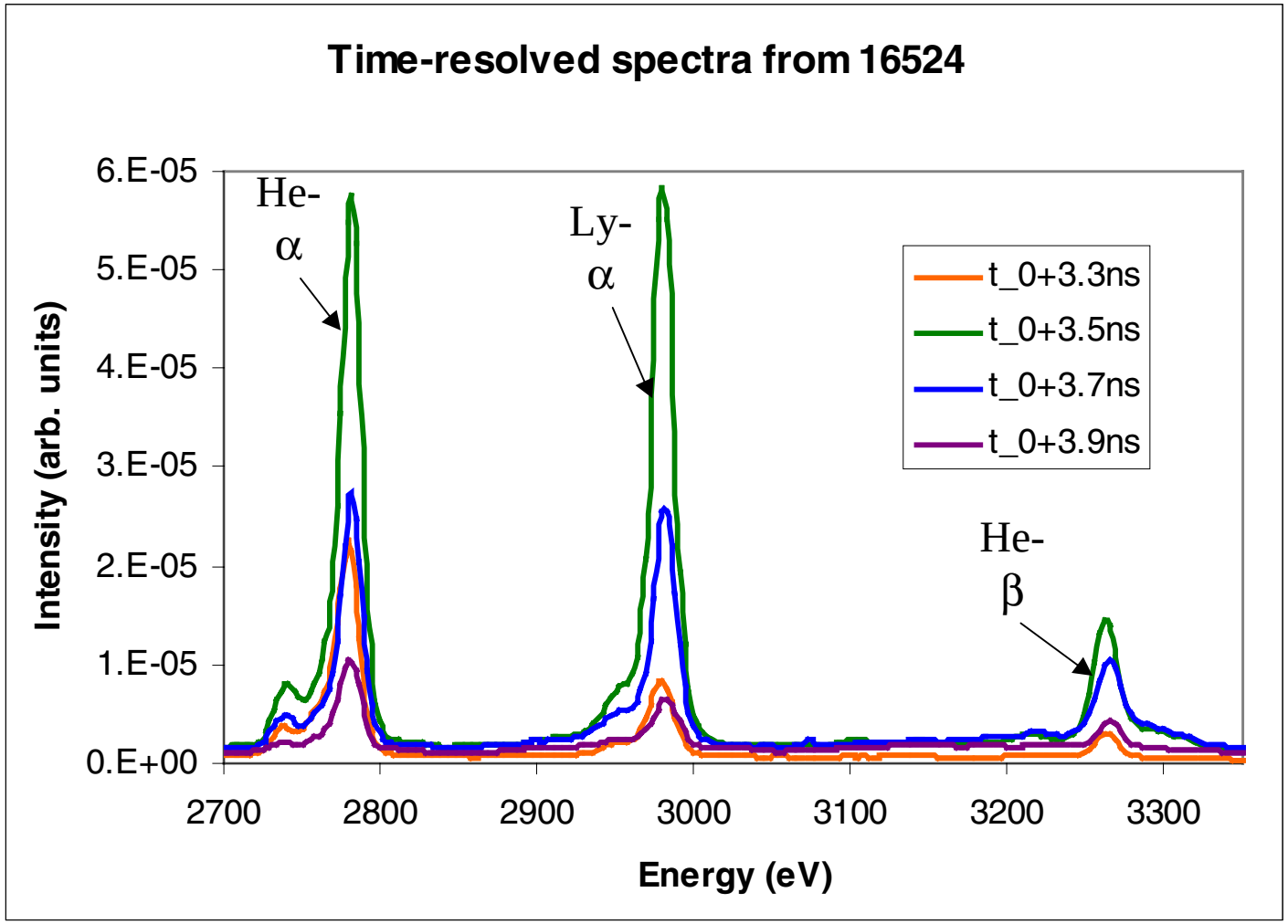
- Timing of the LXS data relative to t_0 courtesy of IXRSC and P510s. Since this shot, the LXS's timing fiducial has been rendered more reliable.

- The location of the spectrum at late times required careful removal of the LXS's barrel distortion.

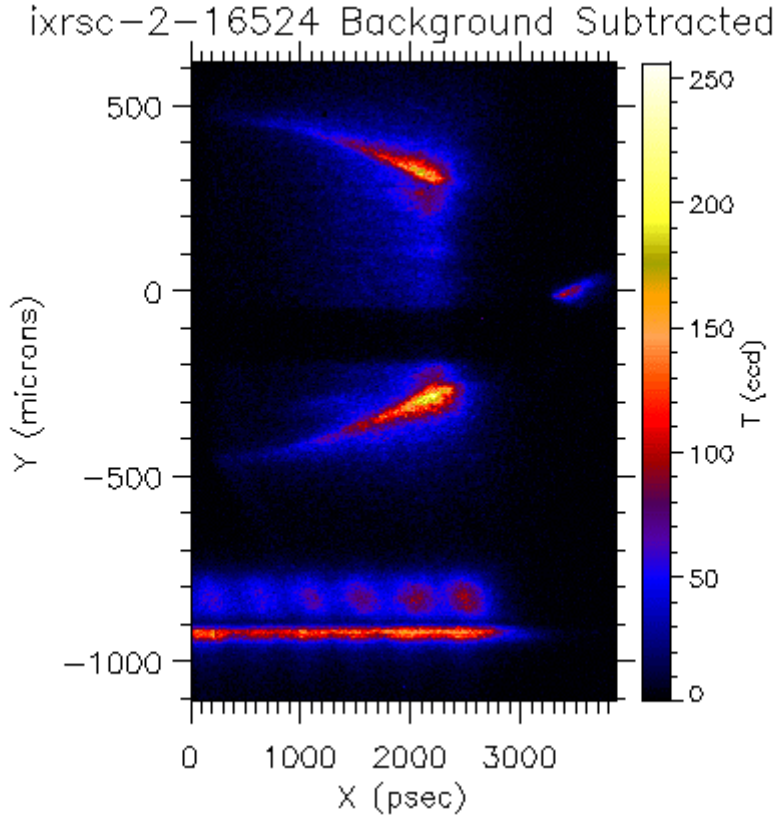
- The core spectrum's evolution indicates a substantially more active temperature history for the core than was true for the marker layer.



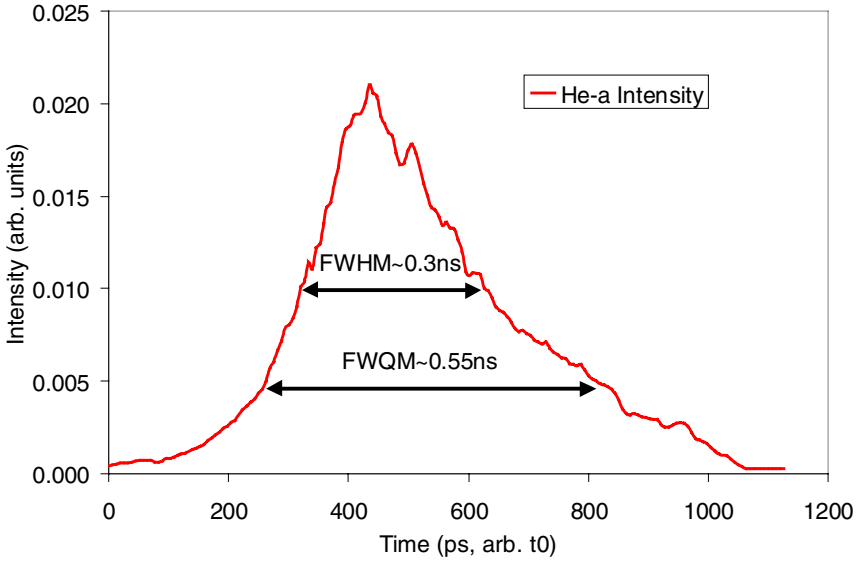
Several lineouts from 16524. Each lineout averages over 180ps

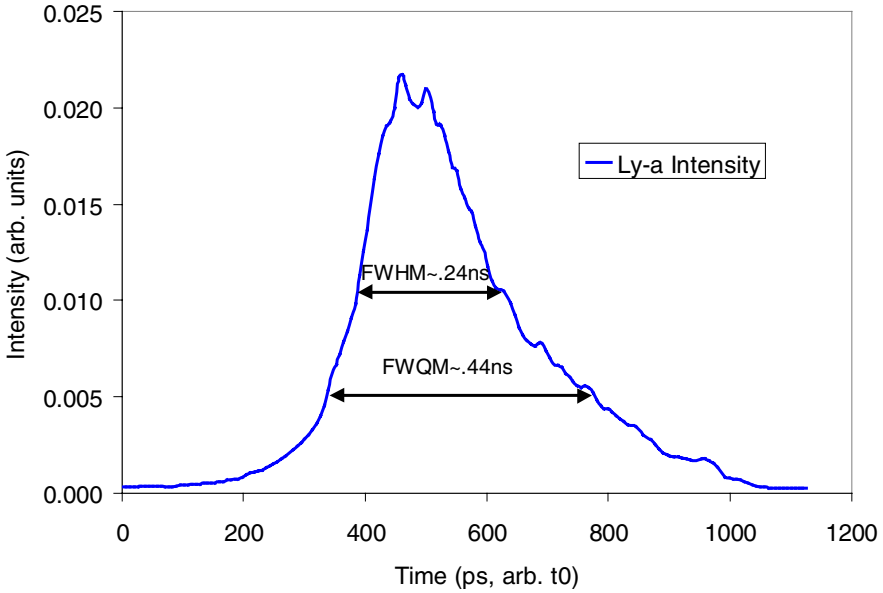


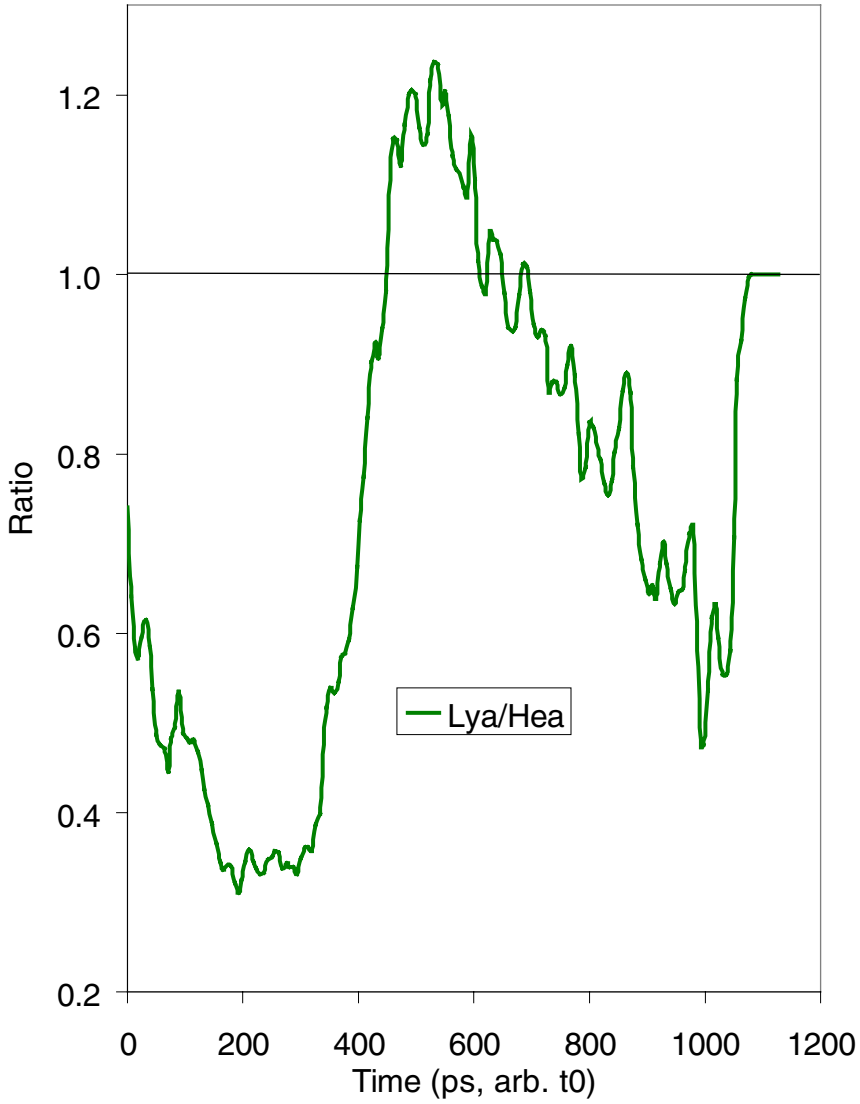
The spatially and temporally resolved IXRSC data from 16524



Duration of line emission as recorded by the LXS is consistent with the data from the XRFC and IXRSC







Conclusions

- The Cl lines are emitted from near-solid density material.
  - Timing and density do not seem to depend on mode number or amplitude of the perturbations applied by target fab.
  - At least two possible explanations: “Delettrez Effect”, or surface roughness
- 1-d nor 2-d simulations which not accounting for laser-speckle induced mix do **not** predict that the marker will achieve temperatures sufficient to cause the marker layer to emit in the Cl K-shell, and certainly not the Lyman series.