Application of Stark-broadened Line Shapes to the Analysis of Line Absorption Spectra

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Outline

- Ti line absorption model including opacity and line self-emission.
- OMEGA implosion experiment with Ti-doped tracer layer embedded in the shell.
- Absorption line shapes in He- and Li-like Na.
- Z experiment with NaBr layer tampered in a plastic slab.
- Summary.

Ti line absorption model

- The optical depth is written as:

$\tau_\nu = \pi e^2/mc(\Sigma f_{ij}\phi_\nu F_i)N\Delta R$

- The sum over line transitions includes all contributions from $n=1$ to $n=2$ transitions in F- to He-like Ti ions.

- The optical depth is density and temperature dependent through the temperature and density dependence of the fractional populations, and the density dependence of the Stark-broadened absorption line shapes.

- Transmission model: $I_\nu = I_o e^{-k\nu L}$, $L=\Delta R$.

Ti ions: energy levels and line transitions

- In each ion, all J-levels and fine-structure line transitions involving configurations with electrons in $n=1$ and $n=2$ are included.
- e.g., for Be-like Ti relevant configurations are:

  $1s^2\ 2s^2$

  $1s^2\ 2s\ 2p$

  $1s^2\ 2p^2$

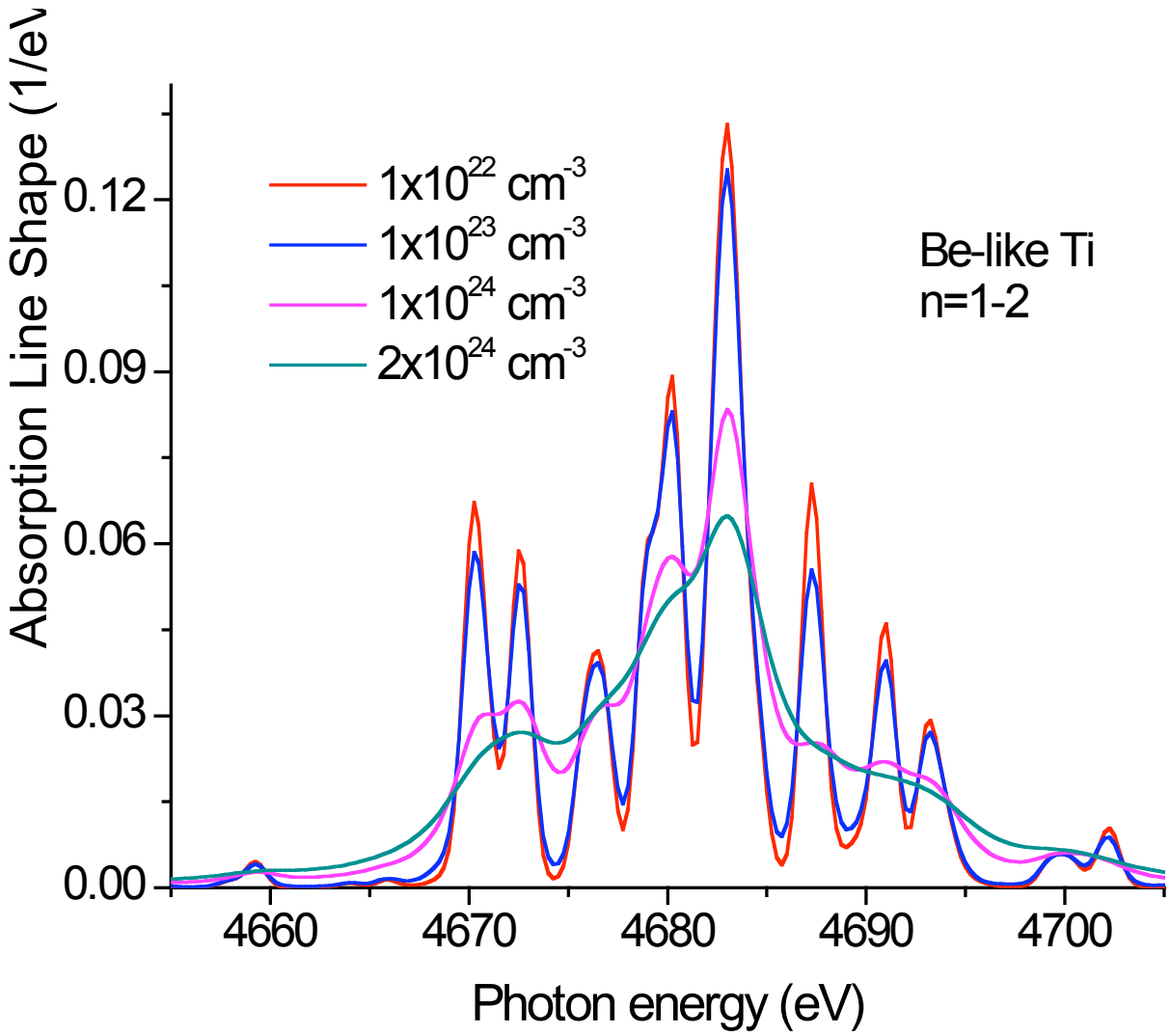
  $1s\ 2s^2\ 2p$

  $1s\ 2s\ 2p^2$

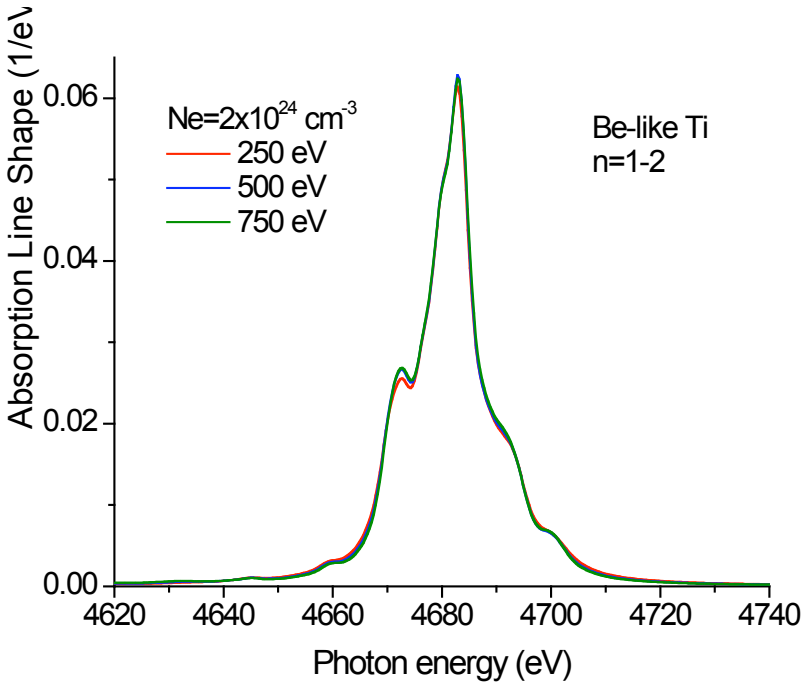
  $1s\ 2p^3$
- Line transition shapes are broadened and blended by the Stark effect.

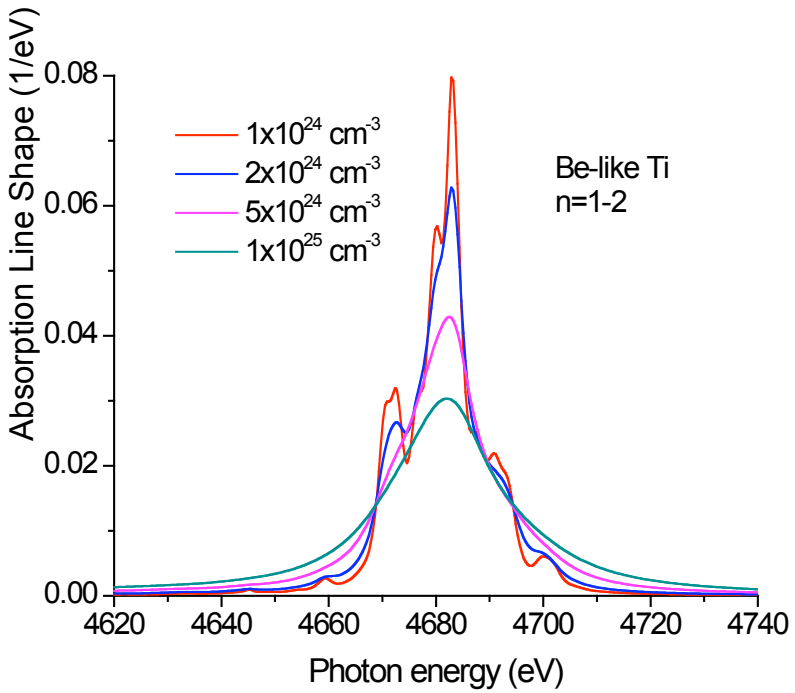
ion	Number of lower J energy levels	Number of upper J energy levels	Number of line transitions
He	1	6	2
Li	3	16	21
Be	10	30	85
B	15	35	165
C	20	30	169
N	15	16	169
O	10	6	22
F	3	1	2

Be-like Ti n=1-2 Stark-broadened line shapes (1)

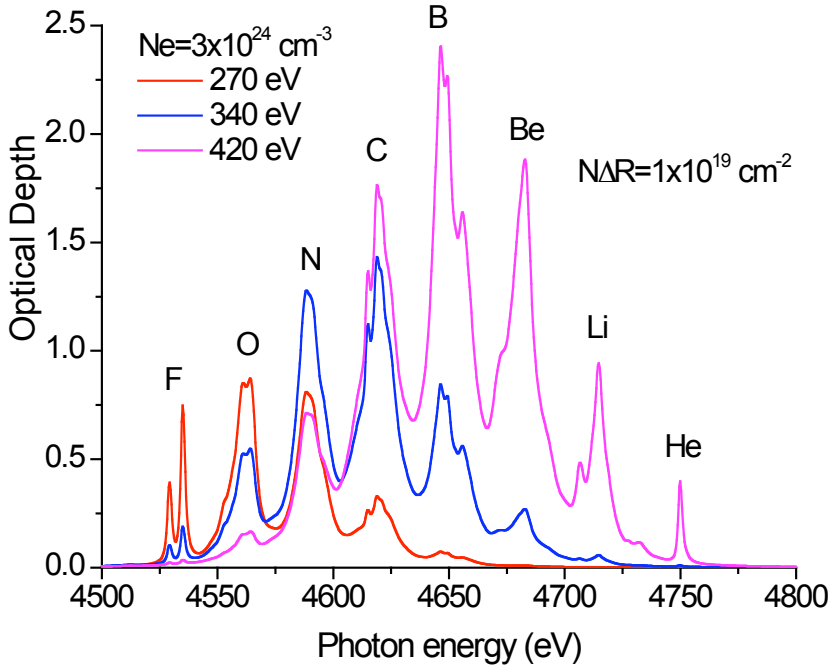


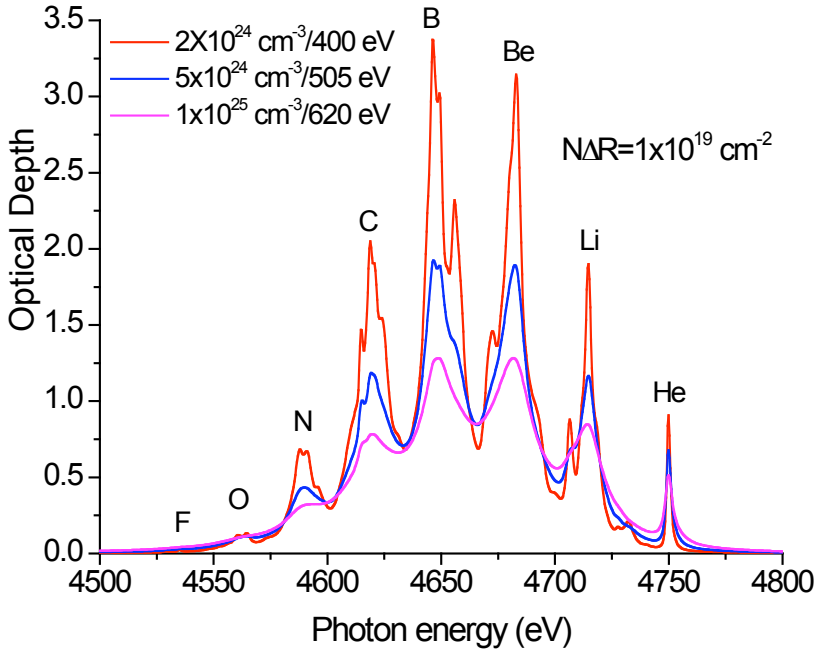
Be-like Ti n=1-2 Stark-broadened line shapes (2)



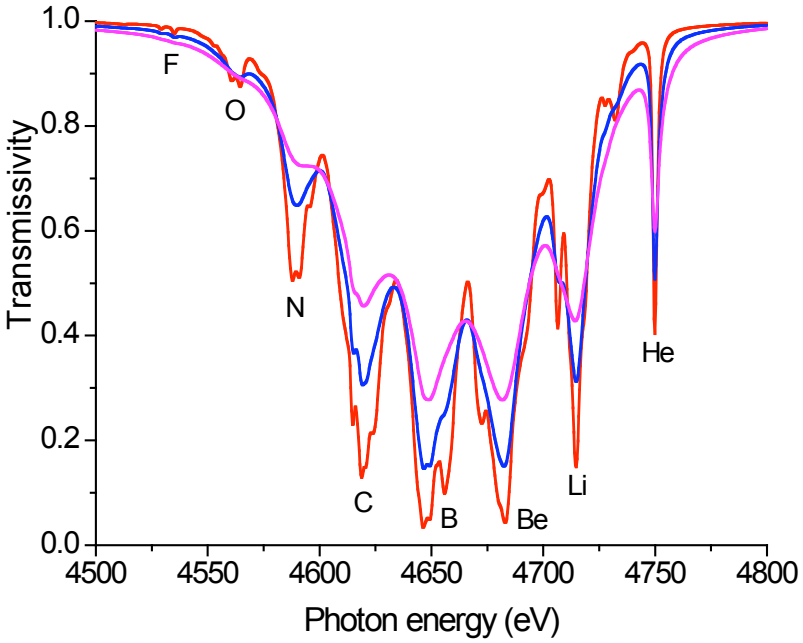


Te and Ne sensitivity of optical depth

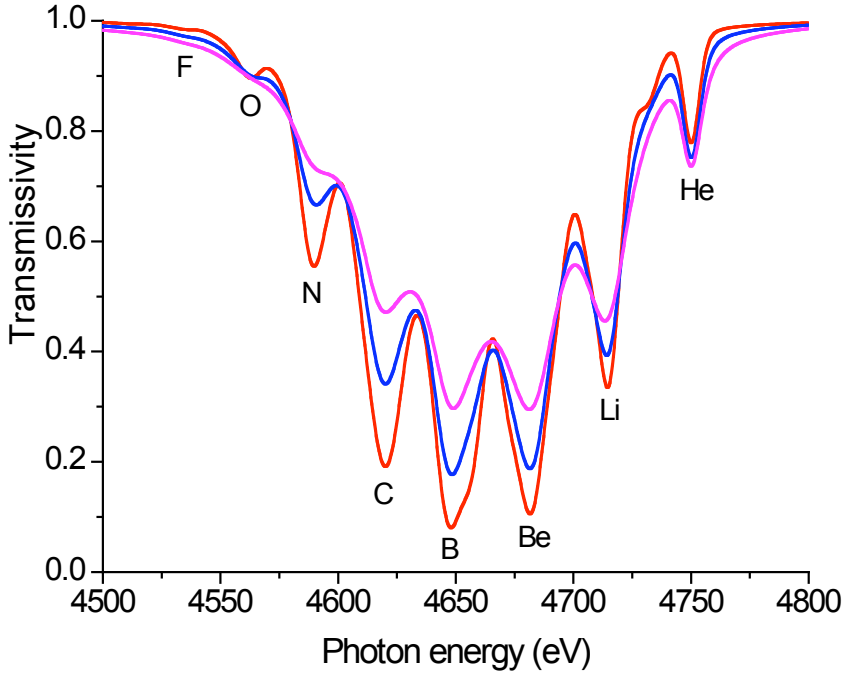




Te and Ne sensitivity of transmission



No instrum. broadening



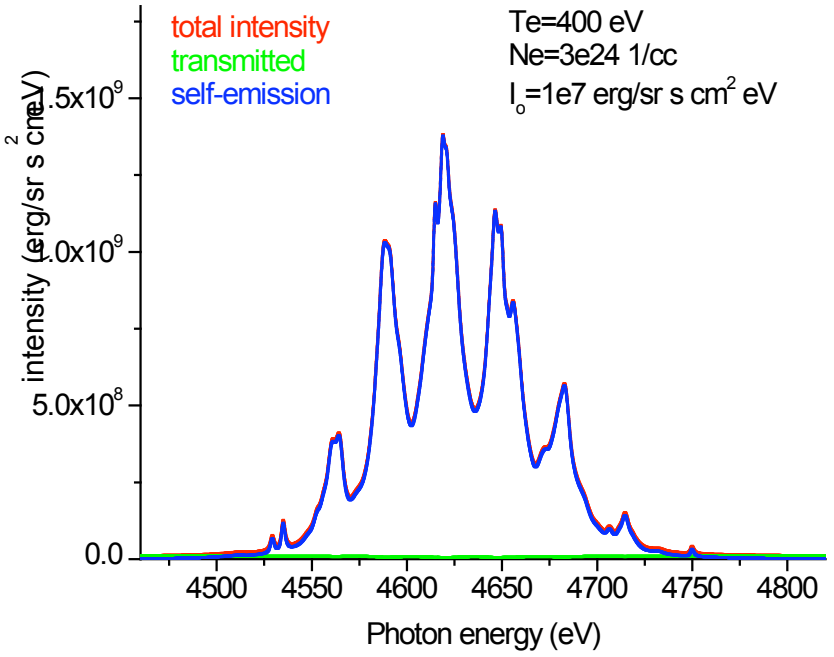
With instrum. broadening
FWHM = 8 eV

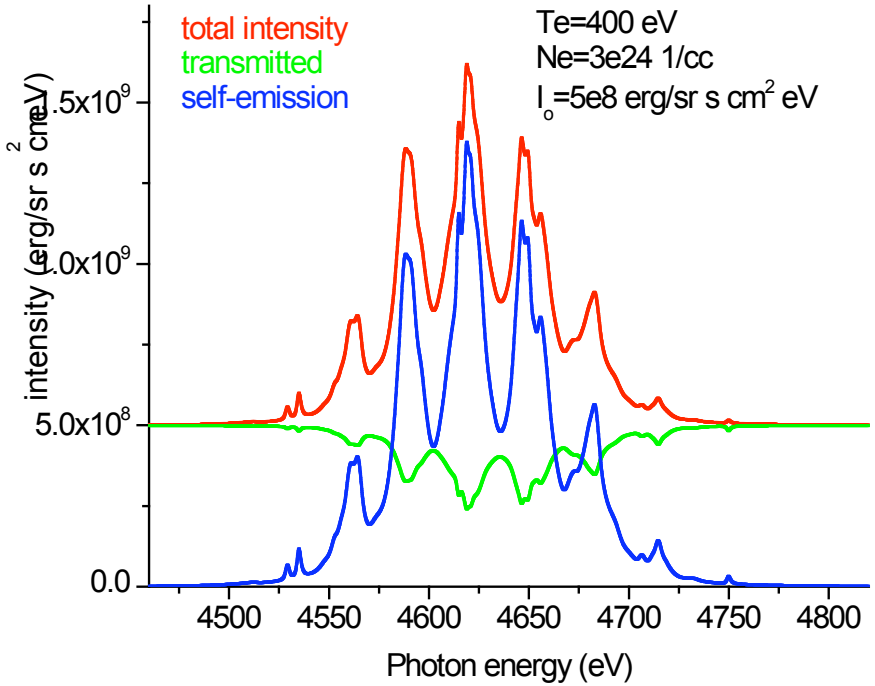
Model extension: include line self-emission

- Solve collisional-radiative atomic kinetics model for level populations including both non-autoionizing and autoionizing levels.
- Atomic data computed with Los Alamos suite of codes: CATS, ACE and GIPPER.
- Include all Ti ionizations stages from Ne- to H-like Ti.
- Model transmitted intensity according to:

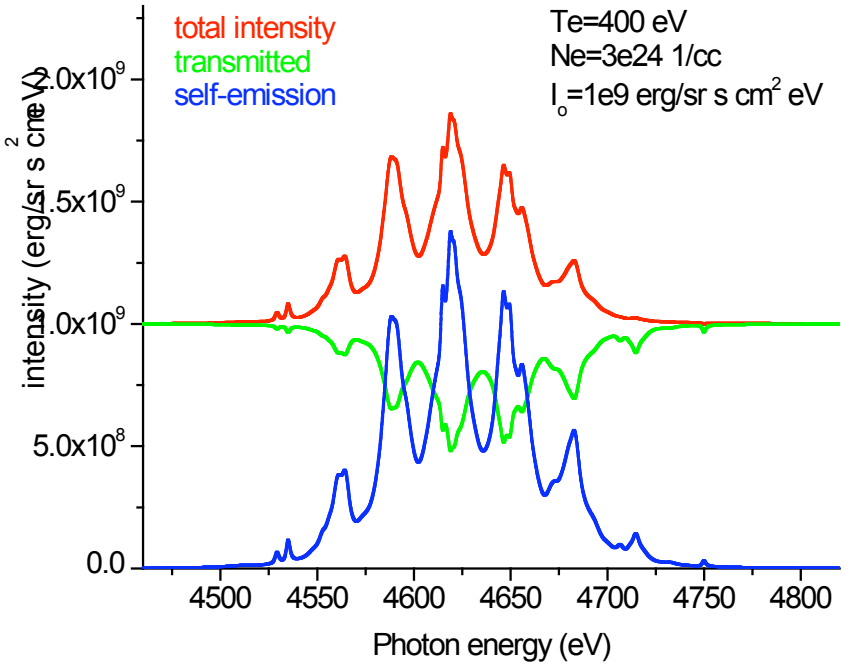
$$I_\nu = I_o\, e^{-k\nu L} + j_\nu (1 - e^{-k\nu L})/k_\nu$$

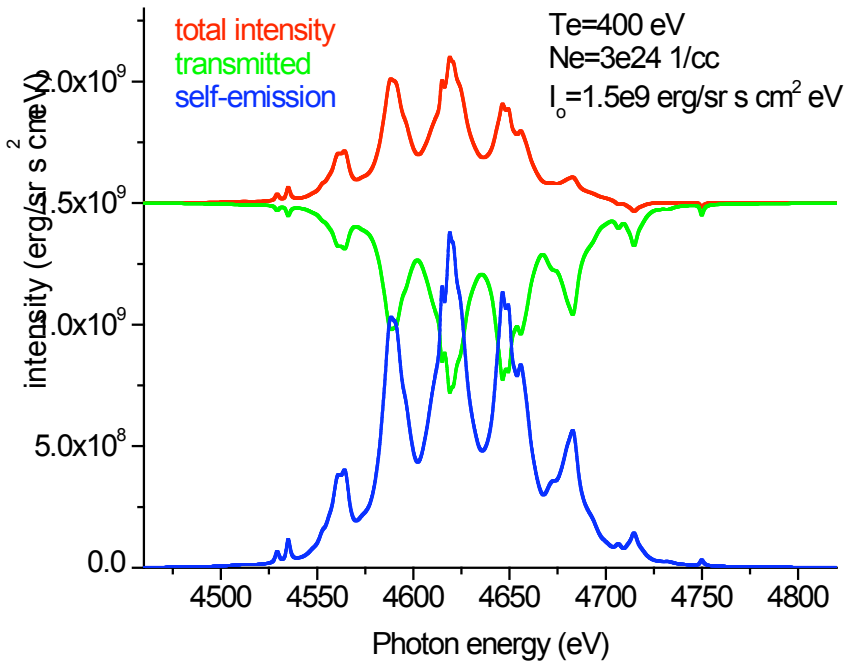
Transmission results (1)



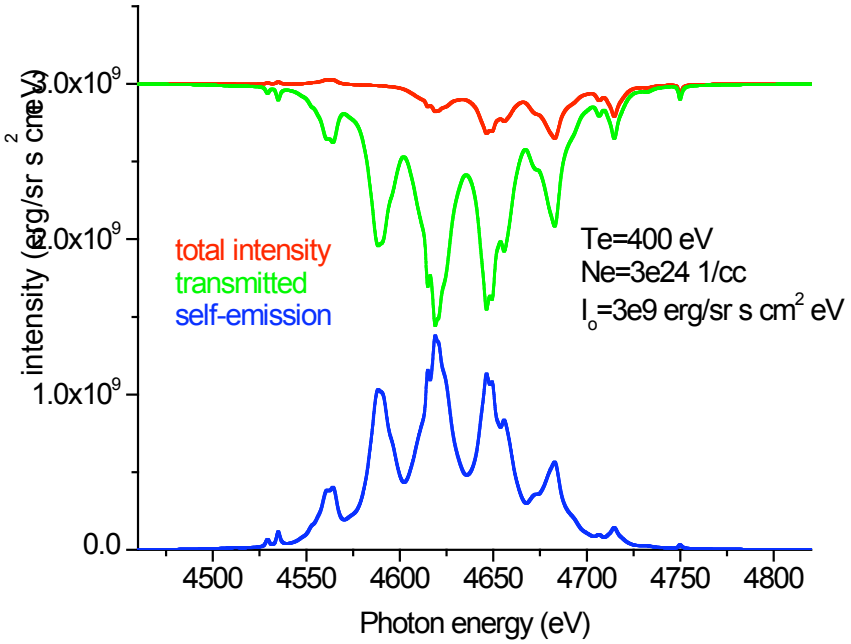


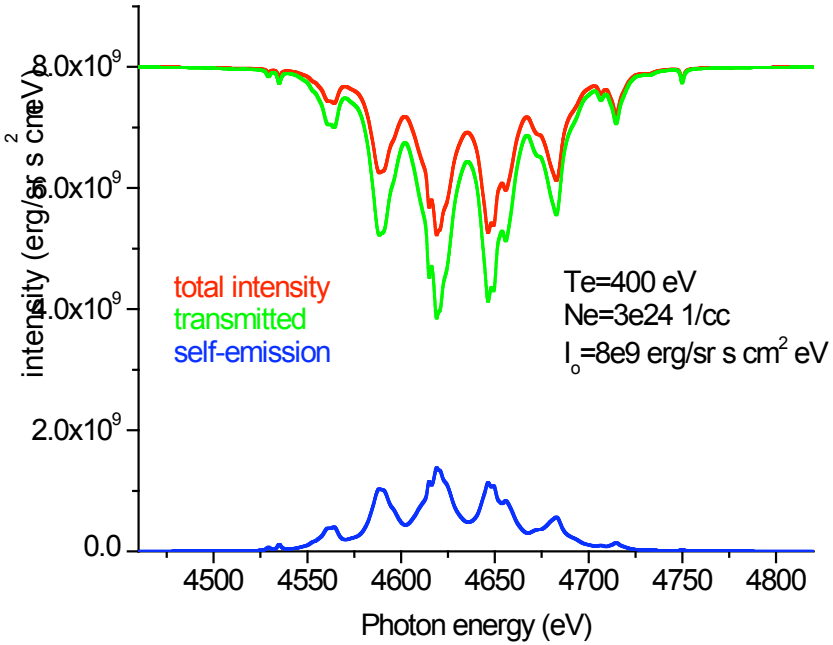
Transmission results (2)





Transmission results (3)





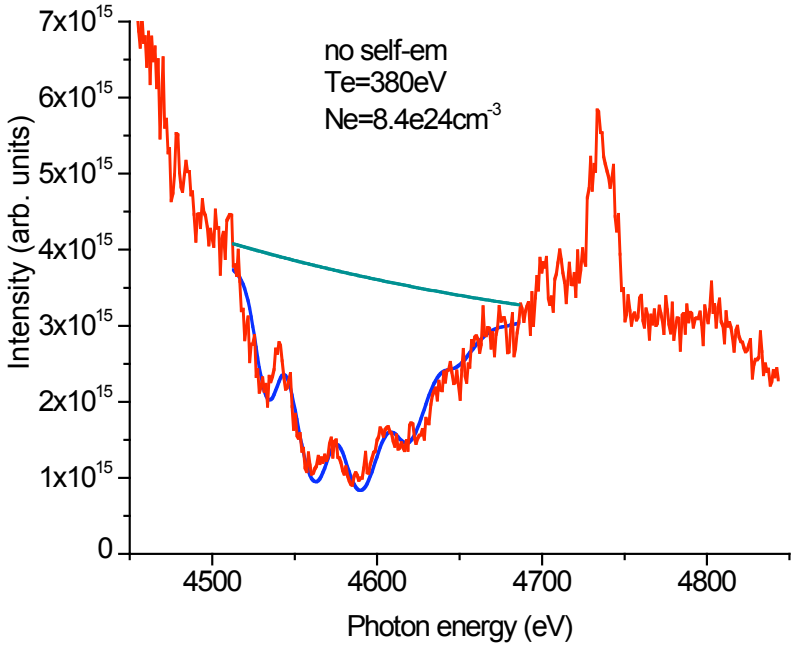
OMEGA implosion experiment (V. Smalyuk, LLE)

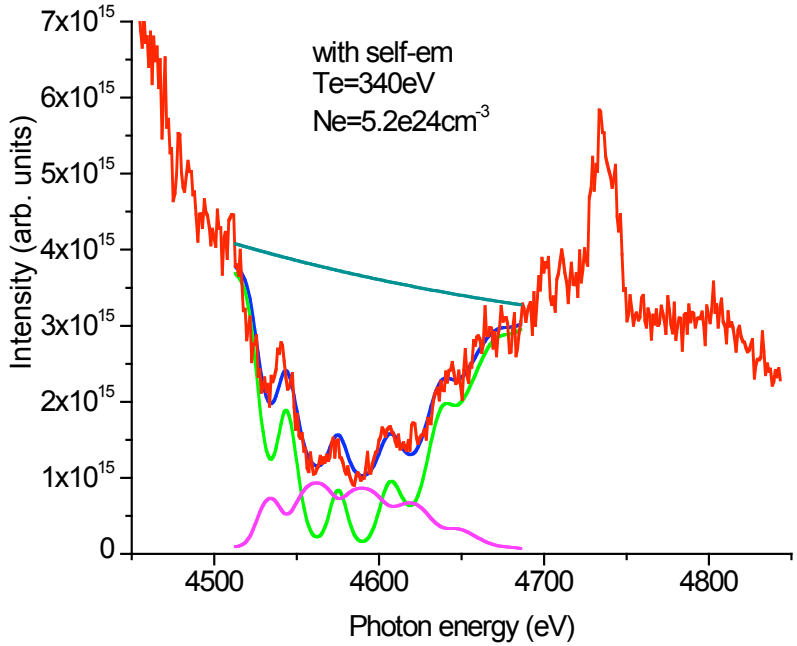
- OMEGA direct-drive implosions, 23kJ UVOT.
- Plastic shells, 20 μm wall thickness.
- Ti-doped (2% atomic) CH tracer layers, 1μm thick, placed at 1, 3, 5, 7 and 9 μm from shell inner surface.
- Core continuum backlights tracer layer, Ti n=1-2 line absorption recorded with streaked spectrometers.
- Resolution power ~ 700.

Analysis with/without self-emission effect

- No self-emission: $I_\nu = I_o e^{-k\nu L}$
- L is obtained from least-squares-minimization fit.
- With self-emission: $I_\nu = I_o e^{-k\nu L} + a j_\nu (1 - e^{-k\nu L})/k_\nu$
- L and a are obtained from least-squares-minimization fit.
- Note: for a given set of I_ν^{exp}, I_o, k_ν and j_ν there is a unique solution for L and a.
- I_o is determined from the data.

Ti self-emission effect on analysis results

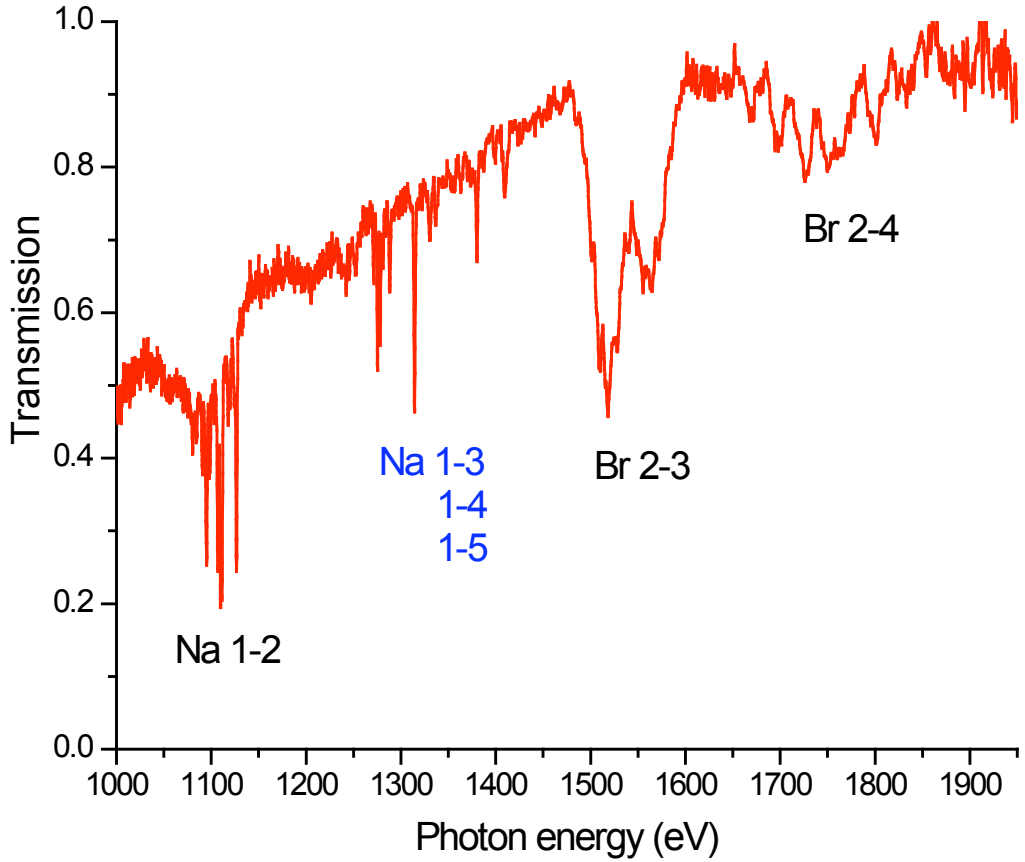




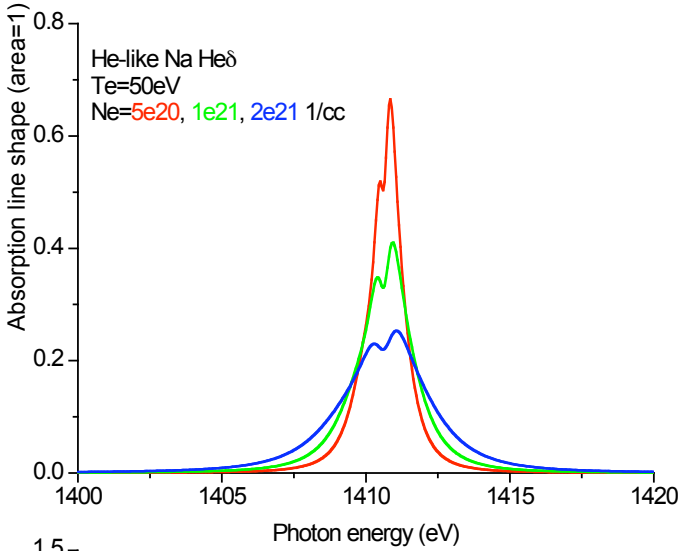
NaBr experiment at Z (J. Bailey, SNL)

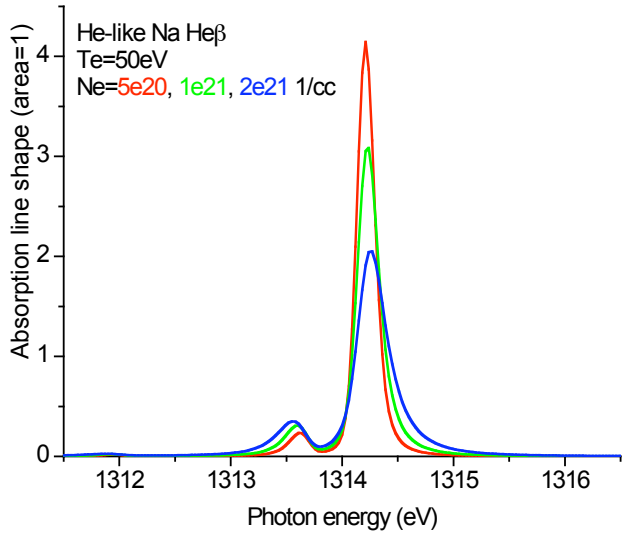
- 1500 Å NaBr layer embedded in a 1.96 μm / 2.07 μm plastic (CH) slab
- Radiatively heated and backlighted by z-pinch, located at 42 mm from z-pinch axis.
- Te = 50eV, Zbar (Na) ≈ 9, Zbar (Br) ≈ 10.5.
- Observation of Na K-shell and Br L-shell, n = 2 — 3, absorption lines.
- Time-integrated, spectral resolution power ~ 1000.

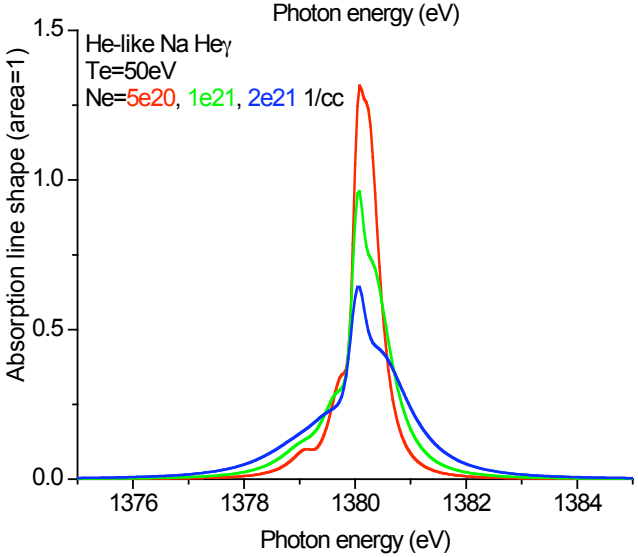
Z shots z535/z536 NaBr absorption spectra

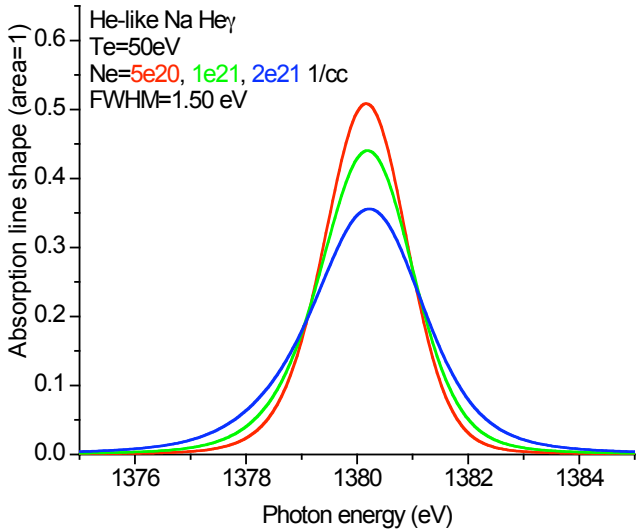


Stark-broadened He-like Na line shapes



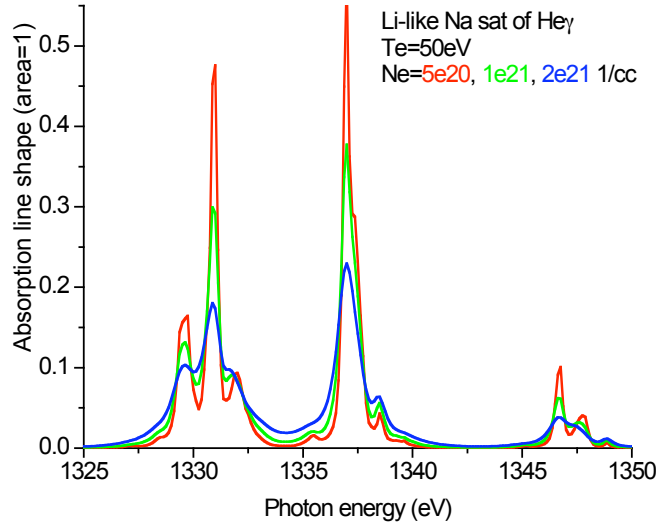


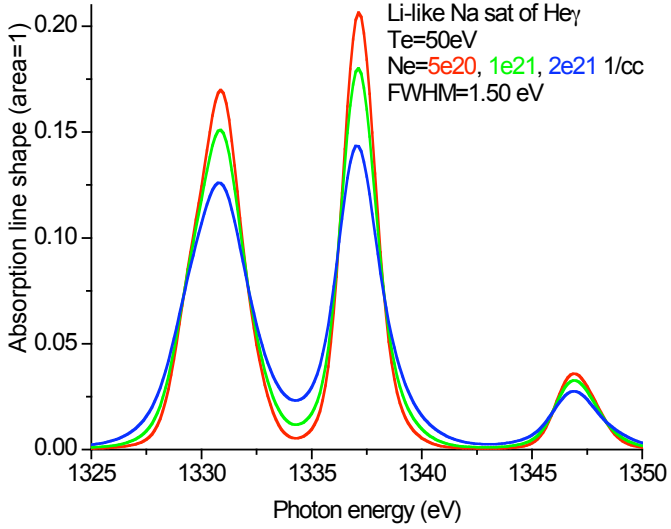




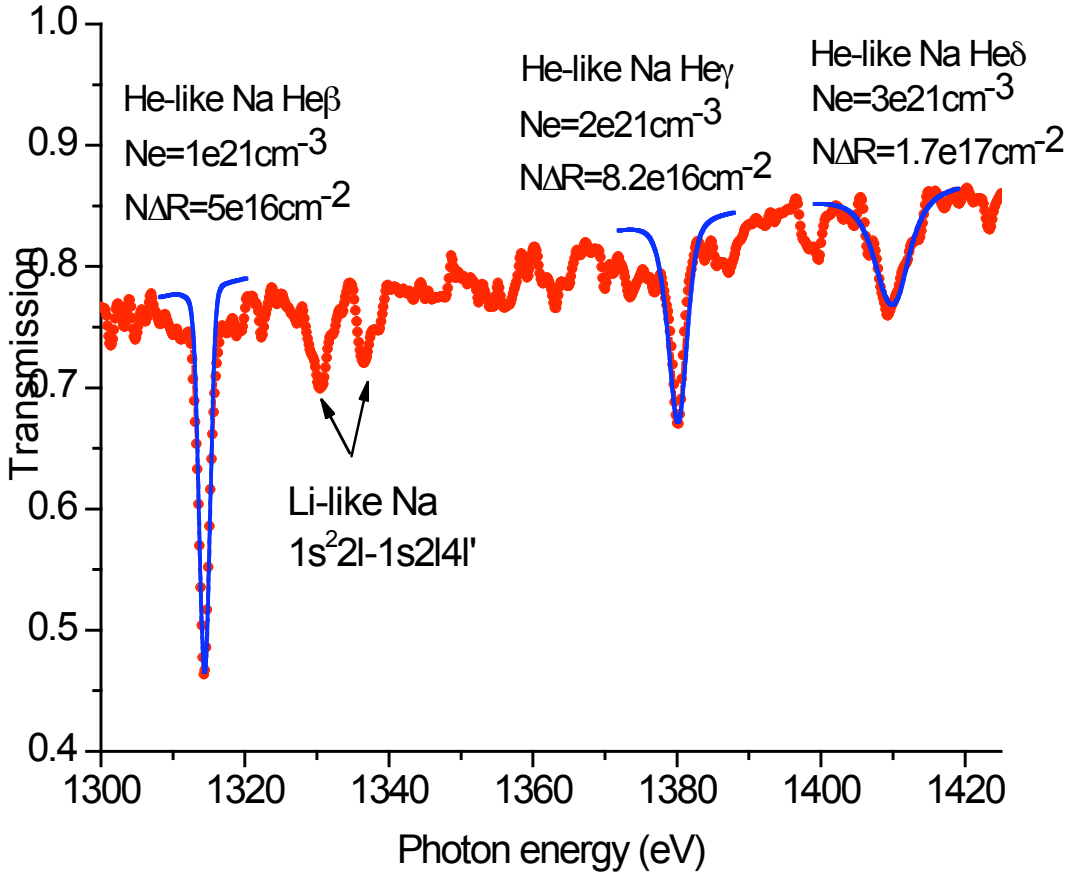
Stark-broadened Li-like Na line shapes

- Li-like Na satellites of Heγ line.
- $1s\ 2l\ 4l' - 1s^2\ 2l$
- $l = s, p$
- $l' = s, p, d, f$
- 3 lower J energy levels.
- 98 upper J energy levels.
- 64 fine-structure line transitions.
- Line transition shapes are broadened are blended by the Stark effect.





Preliminary results: He-like Na absorption lines



Summary

- Application of Stark-broadened line shapes to analysis of line absorption data.
- Dependence of Stark-broadening on density can provide information on density of sample.
- Two application cases:
  - Ti 1-2, Ti-doped tracer layer in plastic shell,
  - He-like Na 1-3, 1-4 & 1-5, and Li-like Na sat of Heγ, NaBr layer embedded in plastic slab.
- Preliminary results are encouraging.