Application and Analysis of the Isoelectronic Line-Ratio Temperature Diagnostic in a Planar Ablating-Plasma Experiment at the National Ignition Facility

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Shot N150520: 23° and 30° beams
NIF x-ray spectrometer streaked spectrum
(uncalibrated)

Photon energy (keV)

Time (ns)

Co He\(_\alpha\) + Mn He\(_\beta\)
Mn He\(_\alpha\)

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Summary

The isoelectronic Co/Mn He\(_\alpha\) line ratio is a good temperature diagnostic for ablating plasmas

- The Co/Mn He\(_\alpha\) line ratio was used to measure the electron temperature in planar experiments performed to study the beam angle-of-incidence dependence of the two-plasmon–decay (TPD) instability
- The density sensitivity of this line ratio is a source of systematic error and a consideration in choosing microdot materials
- Spectrum simulations show that the He\(_\alpha\) line ratio is only modestly affected by self-absorption
Collaborators

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Temperatures in two planar experiments performed at the National Ignition Facility (NIF) were inferred from isoelectronic line ratios from embedded Co/Mn microdots.

Shot N150520: 23° and 30° beams (32 beams total)
Shot N150521: 45° and 50° beams (60 beams total)

• PrismSPECT* for parameter \((T_e, \rho)\) surveys
  – detailed atomic modeling
  – self-absorption modeled as local photon-escape probabilities in spherical geometry

• Spect3D* simulations include the same detailed atomic model plus
  – microdot conditions obtained from \(T_e, \rho\) histories from DRACO CH foil simulations
  – realistic microdot geometry with the actual 7° viewing angle
  – nonlocal coupling of radiation with atomic kinetics

*Prism Computational Sciences, Inc., Madison, WI 53711.
Spectra were measured through the entire duration of the laser pulse by the NXS spectrometer.

- Only the Mn and Co emission are simulated
- Line ratios are based on 200-eV spectral integrals

- NIF x-ray spectrometer streaked spectrum (uncalibrated)

- NXS calibrated spectrum at 2.4 ns

- DRACO/Spect3D Meaured

- Density = \( n_c / 10 \)
Consistent Co/Mn microdot line ratios have been obtained using DRACO $T_e$, $\rho$ trajectories with PrismSPECT and Spect3D modeling.

- Spect3D simulations, including nonlocal radiation transport, are based on the axially expanded microdot shape and the actual $7^\circ$ viewing angle.
- Very similar results are obtained for free-escape, local, and nonlocal photon-transport modeling.
The isoelectronic He$\alpha$ line ratio* is primarily a function of electron temperature $T_e$, depending weakly on $n_e$ and optical thickness.

- The measured Co/Mn He$\alpha$ line ratio indicates $T_e \approx 4$ keV at $n_c/4$, compared to $T_e \approx 3$ keV predicted by DRACO CH foil simulations.

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There is little effect of self-absorption on the Co/Mn He\(_\alpha\) ratio for quarter-critical microdot conditions

- Use microdot-scale spheres to test the effects of self-absorption on optically thick lines
  - line attenuation
  - pumping of the He\(_\alpha\)-emitting states

\[ \rho = 8.7 \text{ mg/cm}^3 \]

\[ n_e = n_c / 4 \]

Radius \( R \)

- The supply of emitted He\(_\alpha\) photons is determined by the 1s–2p collisional excitation rate
- He\(_\alpha\) photon absorption is followed by re-emission with near-certain probability
Temperature measurement based on the Co/Mn line ratio does not require a stringent density constraint.

- Temperature measurement from density-dependent line ratios requires some prior knowledge of the density.
- Alternative microdot materials offer higher temperature sensitivity at the expense of higher-density sensitivity.

Assume the line ratio is measured to 10% precision:

\[ \frac{\delta T}{T_e} = \text{5 mg/cm}^3 \]

\[ T_e = \text{3 keV} \]
The isoelectronic Co/Mn He$\alpha$ line ratio is a good temperature diagnostic for ablating plasmas

- The Co/Mn He$\alpha$ line ratio was used to measure the electron temperature in planar experiments performed to study the beam angle-of-incidence dependence of the two-plasmon–decay (TPD) instability.
- The density sensitivity of this line ratio is a source of systematic error and a consideration in choosing microdot materials.
- Spectrum simulations show that the He$\alpha$ line ratio is only modestly affected by self-absorption.
He$\alpha$ line ratios from lower-Z elements, e.g., V/Sc, are more temperature sensitive than Co/Mn

- Density 0.005 g/cm$^3$
- Temperature dependence is primarily from ionization balance and collisional 1s–2p excitation
- Mn and V He$\alpha$ are not in the same NXS channel
The total $\delta T$ temperature estimate uncertainty depends on the line ratio measurement uncertainty $\delta r$ and also on a density constraint $\delta \log_{10} \rho$.

Assume a line-ratio measurement precision: $\delta r = 0.1$

Select the Co/Mn isoelectronic line ratio

• Density 0.005 g/cm$^3$, temperature $\approx$ 3.0 keV