Laser and diagnostic geometry

- Diagnostics are timed coincident with E29270
- Sc K-shell, Ge L-shell spectra collected by X-ray images of self-emission constraint and a quasi steady-state temperature

Planar targets produce uniform, uniaxially expanding plasma and a quasi steady-state temperature [1]

- Schematic of laser-produced plasma reveals uniform, uniaxial expansion
- Sc K-shell, Ge L-shell spectra collected by elliptical crystal spectrometers (MSPEC) [2] and coupled to four-frame X-ray framing cameras (XRFCs)
- Diagnostics are designed to coincide with isothermal expansion predicted by 1-D hydrodynamic simulations (right)

X-ray images of self-emission constraint n_i(t)

- Average ion density n_i is inferred from time-resolved pinhole images of emission parallel and perpendicular to the target normal (TN)
- Measurements of height and radius from three equivalent shots demonstrate the repeatability of the platform prior to target disassembly

Inaccurate collisional or radiative rates will predict inaccurate spectra

- Non-LTE spectra are determined by a balance of competing collisional and radiative processes
- State populations are found by solving coupled rate equations for population n of each state p of all charge states
- The accuracy of the atomic kinetics models is dependent on accuracy of coupled rate equations for population n of each state i of each charge state

Open L-Shell Spectroscopy of Non-Local-Thermodynamic-Equilibrium Plasmas

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Motivation

- Spectra from non-local-thermodynamic-equilibrium (non-LTE) plasmas of open-shell configurations are necessary to benchmark and discriminate between conflicting atomic models
- Recent buried-layer experiments constrain the evolution of temperature T_e and ion density n_i, and record Ge L-shell spectra
- While atomic kinetics models show good agreement with spectra recorded at higher density, they are unable to match data recorded at lower densities

Planar targets produce uniform, uniaxially expanding plasma and a quasi steady-state temperature [1]

- Spectra exhibit Li satellites, He-like W (2p2s → 1s2p), Y (2p2s → 1s2s), and He(g) and Ly_α and Ly_β
- Emission-weighted T_e inferred from fitting Sc spectra to ensemble of single-T_e spectra synthesized by 0-D calculation in the atomic kinetics model, SCRAM [3]

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- Non-LTE spectra are determined by a balance of competing collisional and radiative processes
- State populations are found by solving coupled rate equations for population n of each state p of all charge states
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- Spectra from non-local-thermodynamic-equilibrium (non-LTE) plasmas of open-shell configurations are necessary to benchmark and discriminate between conflicting atomic models.
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Inaccurate collisional or radiative rates will predict inaccurate spectra

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- State populations are found by solving coupled rate equations for population $n$ of each state $p$ of all charge states
- The accuracy of the atomic kinetics models is dependent on accuracy of rate coefficients

Rate equation for population $n$ of excited level $p$ [4]

$$n(p) = \frac{P(p)}{D(p)}$$

$$P(p) = n_e n_+ [n_e K_+(p) + \alpha(p)]$$

$$D(p) = n_e K(p) + A(p)$$

$+$ = ion level
1 = ground level
$K$ = collisional coefficient
$A$ = spontaneous emission rate
$\alpha$ = electron capture rate

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Sc K shell constrains $T_e(t)$, supports spatial uniformity

- Spectra exhibit Li satellites, He-like $W(2p_{3/2} \rightarrow 1s_{1/2})$, $Y(2p_{3/2} \rightarrow 1s_{1/2})$, and He$_\beta$; and Ly$_\alpha$ and Ly$_\beta$

- Emission-weighted $T_e$ inferred by fitting Sc spectra to ensemble of single-$T_e$ spectra synthesized by 0-D calculation in the atomic kinetics model, SCRAM [3]
**SCRAM** accurately predicts the Ge charge-state distribution during 1-D expansion, but discrepancy emerges at late time

- Synthetic Ge L-shell spectra generated at $T_e$, $n_i$ inferred from diagnostics agree with observed spectra at early times

- After onset of radial expansion near 2.5 ns, synthetic spectra indicate substantial recombination, contrary to indications of a steady charge state in observed spectra

### Measured $n_i$, $T_e$

![Graph showing measured $n_i$ and $T_e$ over time](image)

### Prominent Li-like Ge lines

| Energy (eV) | Ion | $|\Psi_i\rangle$ | $|\Psi_f\rangle$ |
|-------------|-----|------------------|------------------|
| 1731        | Li  | $3d_{5/2}$       | $2p_{3/2}$       |
| 1766        | Li  | $3d_{3/2}$       | $2p_{1/2}$       |
| 1810        | Li  | $3p_{1/2}$       | $2s_{1/2}$       |
| 1822        | Li  | $3p_{3/2}$       | $2s_{1/2}$       |

### Emissivity (arbitrary units)

- $T_e = 1500$ eV, $n_i = 7.7 \times 10^{19}$ cm$^{-3}$
- $T_e = 2000$ eV, $n_i = 4.5 \times 10^{19}$ cm$^{-3}$
- $T_e = 2000$ eV, $n_i = 1.9 \times 10^{19}$ cm$^{-3}$
- $T_e = 2000$ eV, $n_i = 9.3 \times 10^{18}$ cm$^{-3}$

**Data**

- SCRAM at $(x, n_i)$

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**E29273**
Discrepancy can be exploited as a mechanism to infer kinetic rates

- The buried layer is a viable platform to investigate recombination rates at densities $n_i < 10^{20}$ cm$^{-3}$

- The accuracy of recombination rates will be inferred from the charge-state distribution of spectra recorded after the end of the drive pulse
  - recombination at different densities can be probed by varying the duration of the drive pulse
References