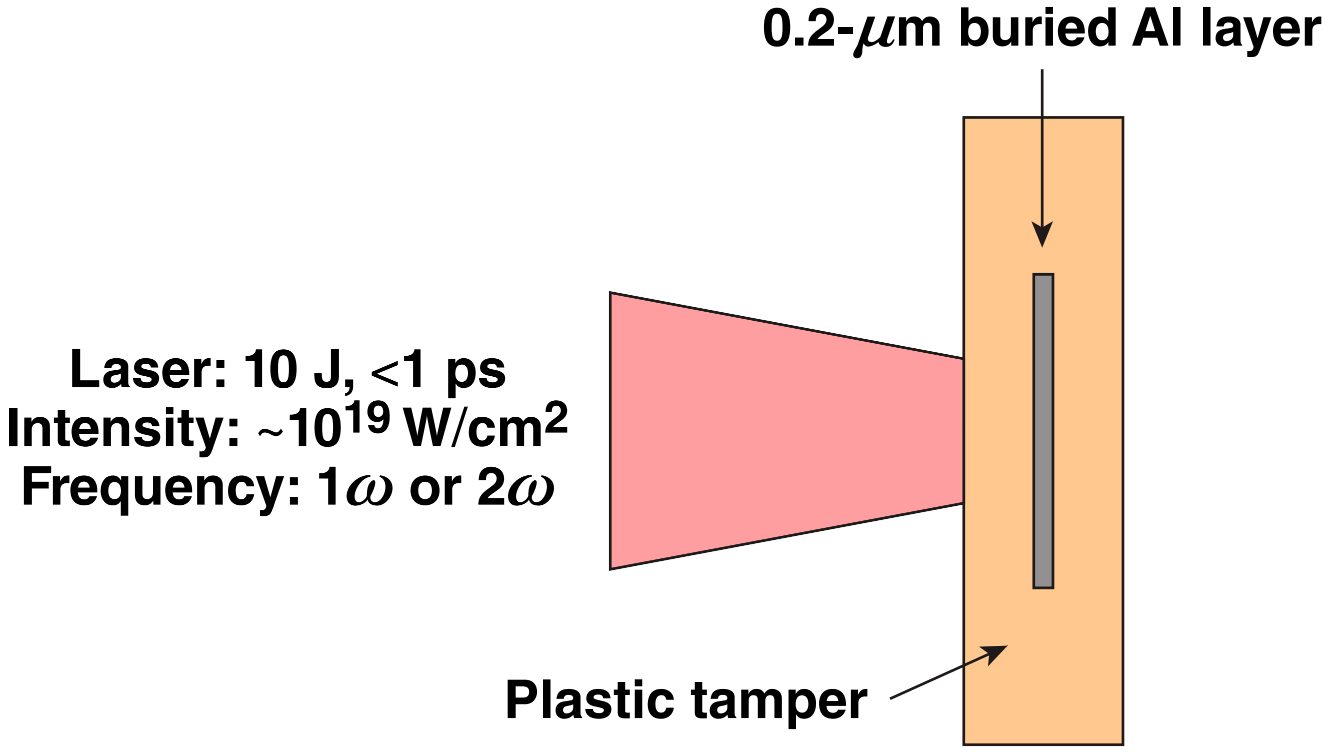
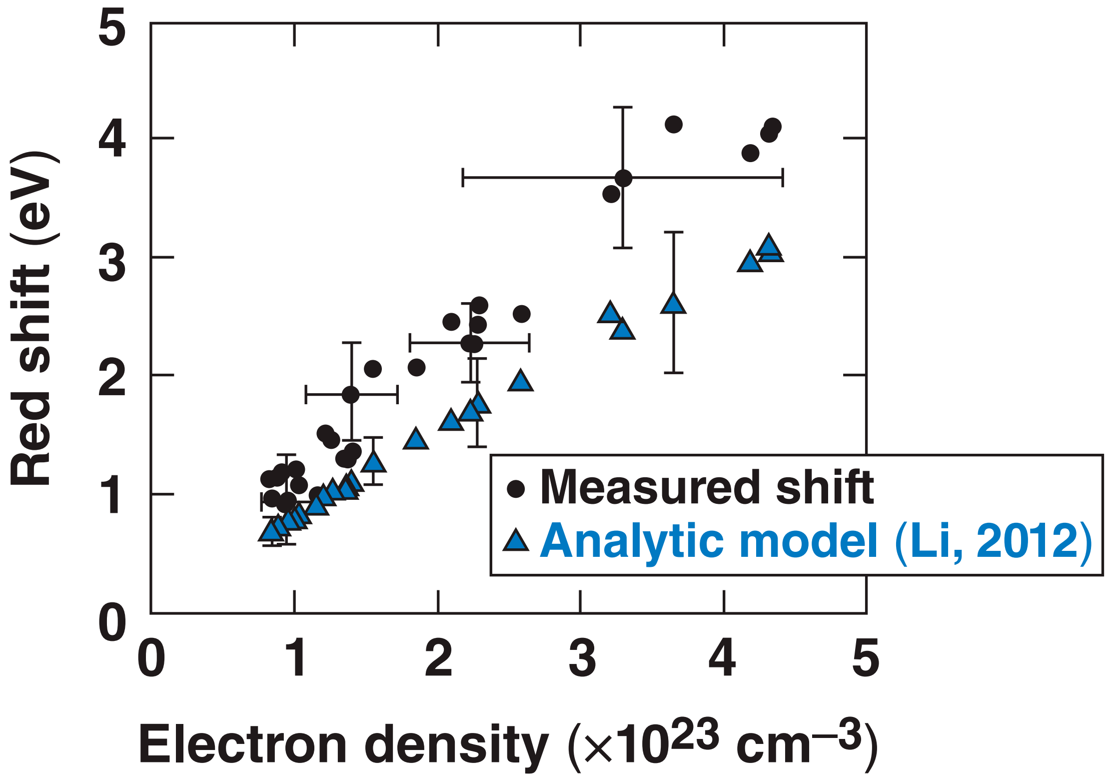
Picosecond Streaked K-shell Spectroscopy of Near Solid-Density Aluminum Plasmas





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58th Annual Meeting of the
American Physical Society
Division of Plasma Physics
San Jose, CA
31 October–4 November 2016

Summary

A linear red shift of the $1s2p$–$1s^2$ transition in He-like aluminum was observed for electron densities between 1 to 5 × 10^{23} cm^{-3}

- High-intensity, short-pulse laser interactions have been used to study dense plasma line shifts
- Picosecond x-ray spectroscopy was used to measure the thermal line emission from a buried aluminum tracer layer
- The plasma conditions were inferred from the thermal line width and satellite-intensity ratio using a nonlocal thermodynamic equilibrium (NLTE) collisional-radiative atomic physics model (*PrismSPECT*)*

The observed line shifts are consistent with an analytic line-shift model based on numerical ion-sphere calculations for dense plasmas.**

*J. J. MacFarlane *et al.*, High Energy Density Phys. 3, 181 (2007).
**X. Li and F. B. Rosmej, Europhys. Lett. 99, 33001 (2012).

Collaborators

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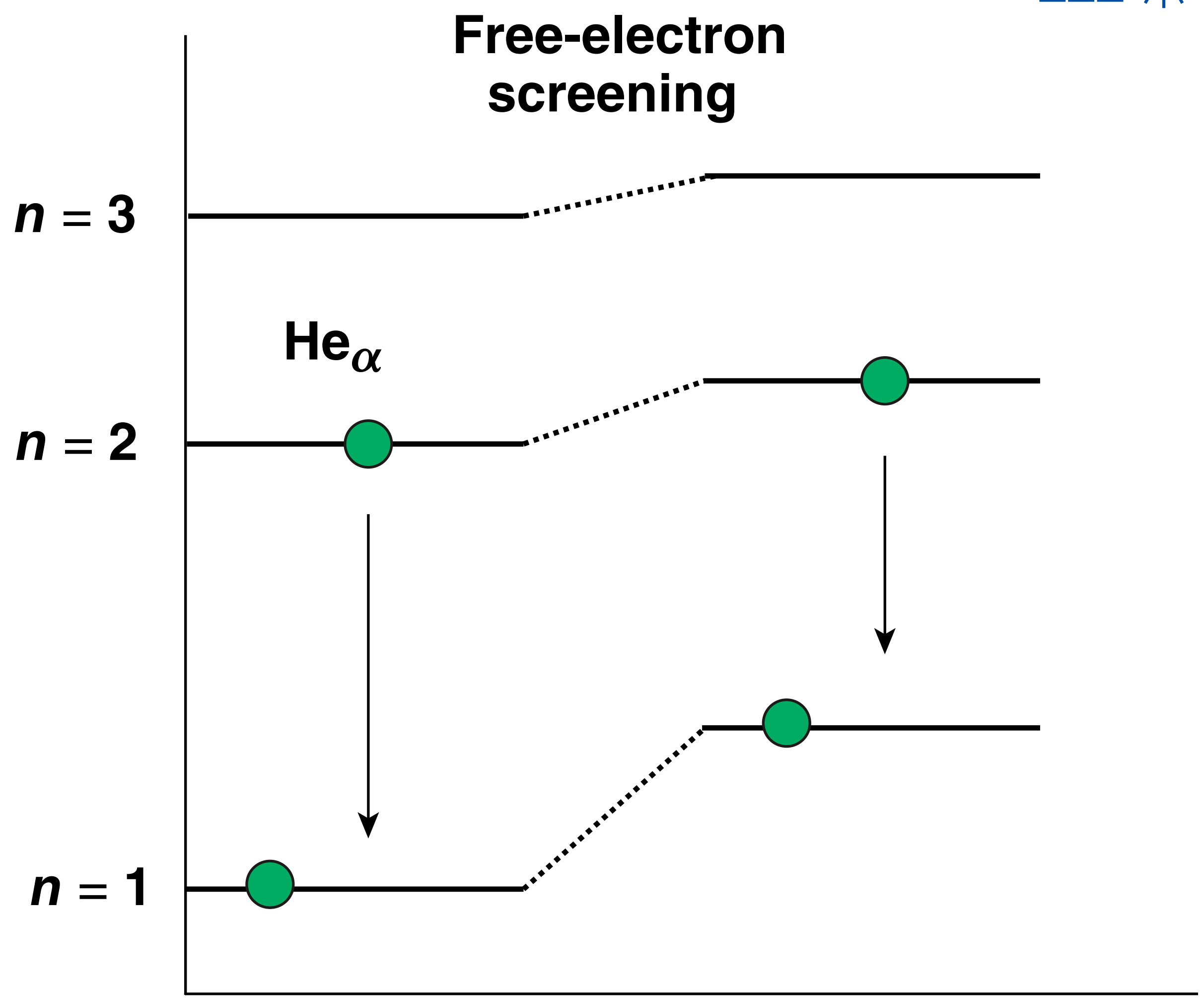
Prism Computational Sciences

Accurate descriptions of plasma-dependent atomic properties are required to understand high-energy-density systems

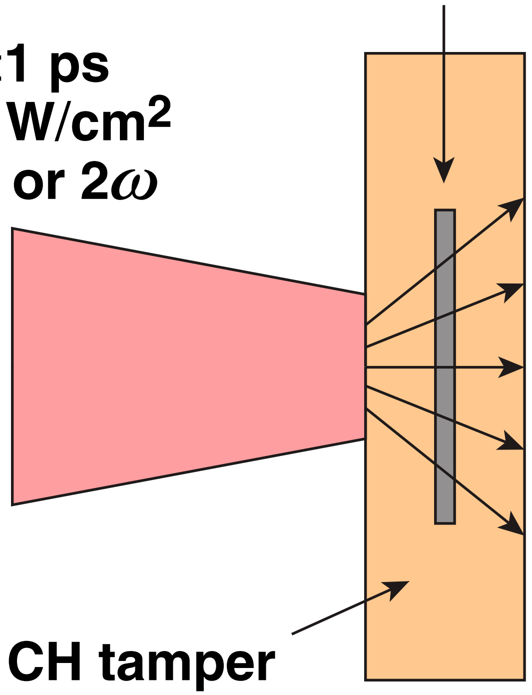
- The radiative and thermodynamic properties of a plasma are modified at high energy density*,**:
  - – nonequilibrium equation of state
  - – pressure ionization and continuum lowering
  - – energy level and spectral line shifts
- Dense plasma line shifts originate from free-electron modification of the ionic potential**,†
  - – free electrons screen the nuclear charge
  - – bound energy levels shift toward the continuum
  - – emission lines shift to lower photon energies



* G. Chabrier, F. Douchin, and A. Y. Potekhin, J. Phys., Condens. Matter 14, 9133 (2002).
** D. Salzmann, Atomic Physics in Hot Plasmas, International Series of Monographs on Physics, Vol. 97 (Oxford University Press, New York, 1998).
† H. R. Griem, Spectral Line Broadening by Plasmas (Academic Press, New York, 1974).

E25605

Experiments using buried-layer targets access the dense, high-temperature plasma regime



- **The buried layer heats through collisional dissipation of a resistive return current**
- **Buried-layer emission is studied with an ultrafast streaked x-ray spectrometer**

The data are compared to simulated spectra to infer the plasma conditions.

* C. R. D. Brown *et al.*, Phys. Rev. Lett. 106, 185003 (2011).
** D. J. Hoarty *et al.*, High Energy Density Phys. 9, 661 (2013).

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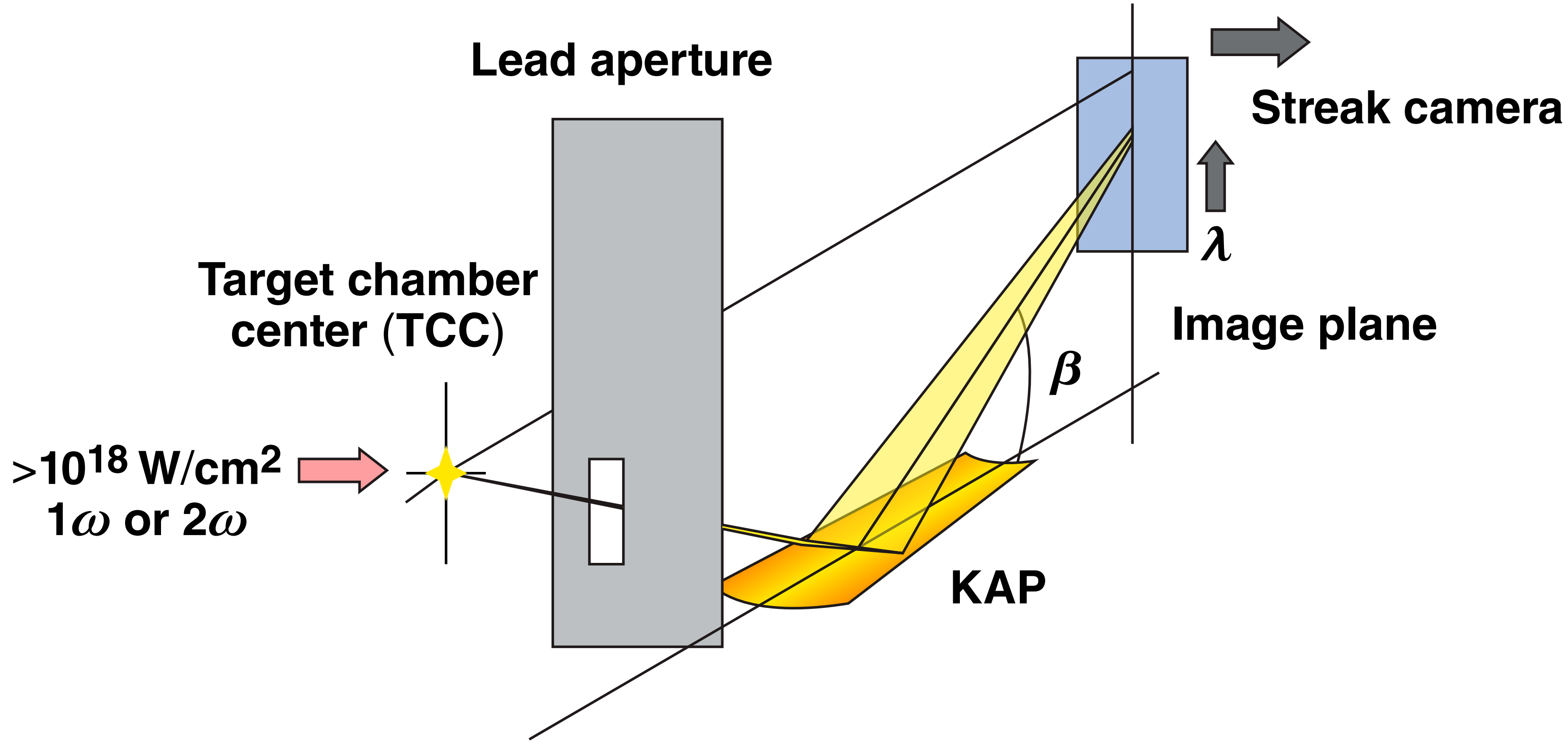
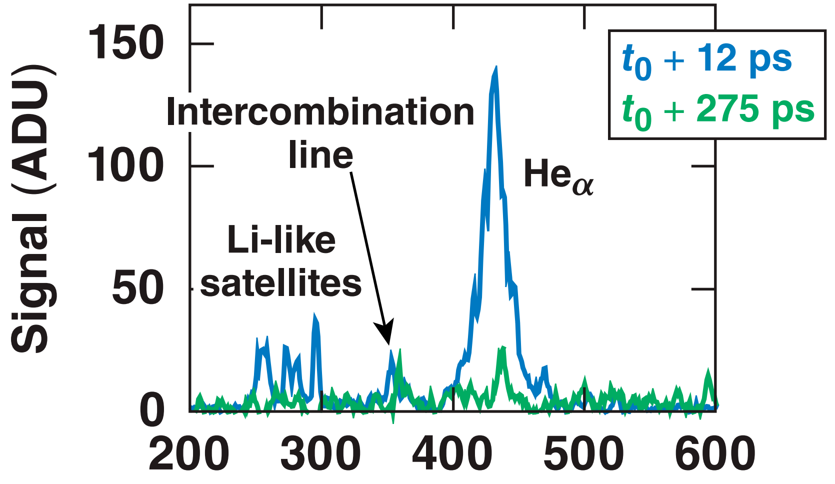
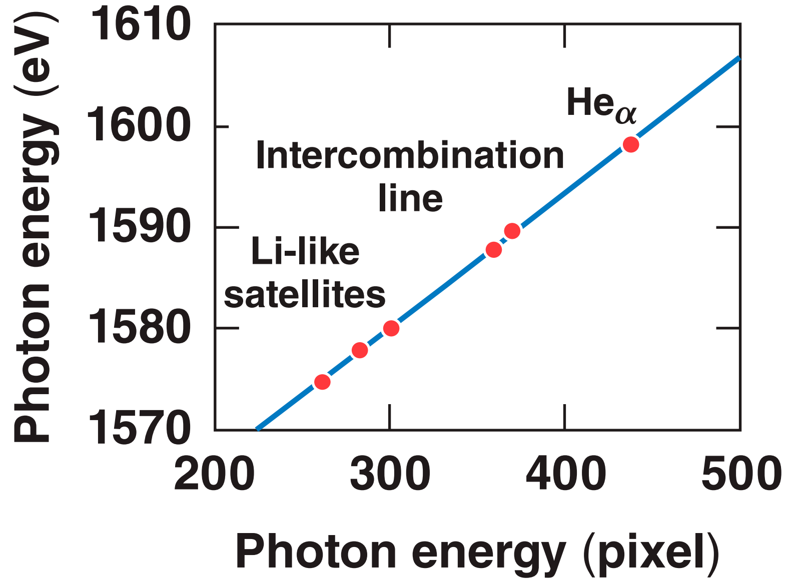
A focusing, time-resolved Hall spectrometer measured He$_\alpha$ emission from a buried aluminum layer







- Conically curved focusing KAP crystal
- Spectral range ±90 eV around Al He$_\alpha$
- Spectral resolution $E/\Delta E$ ~ 800
- Temporal resolution ~2 ps

*T. A. Hall, J. Phys. E: Sci. Instrum. 17, 110 (1984).

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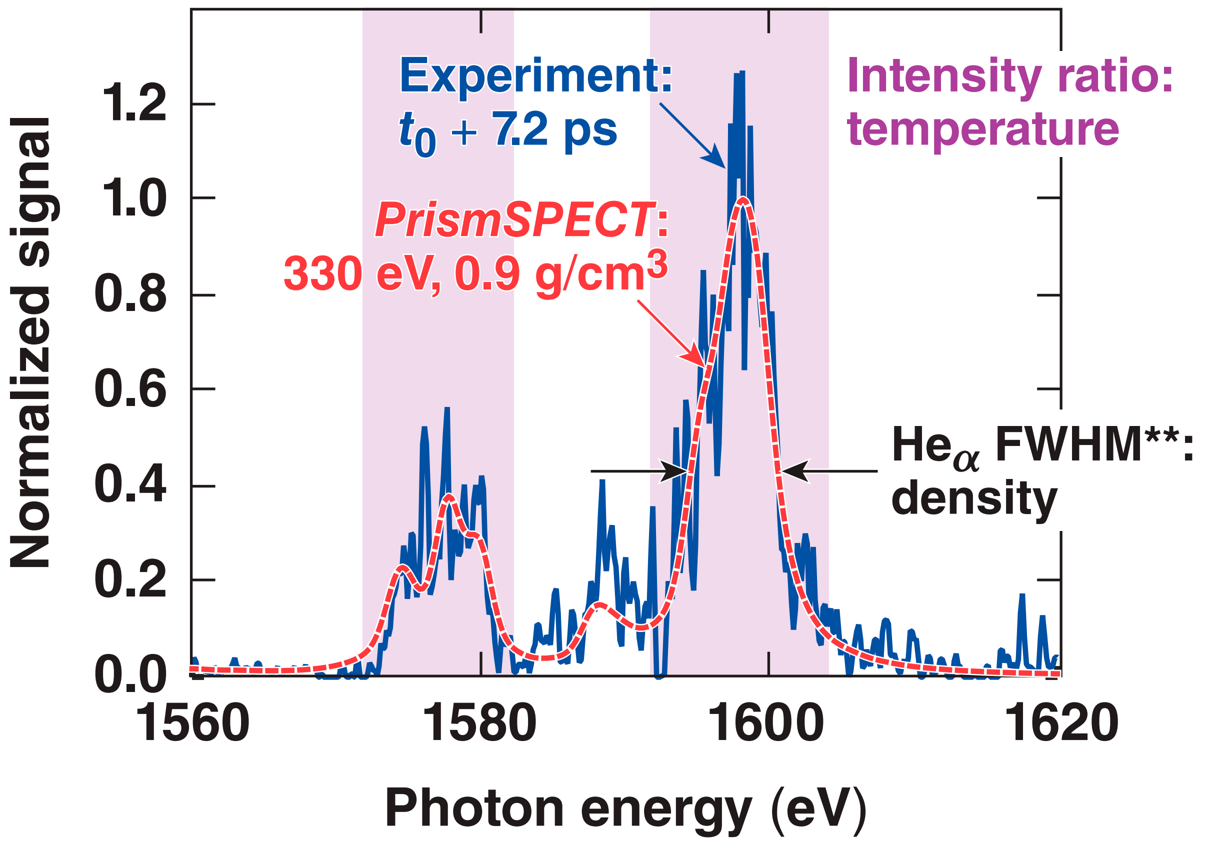
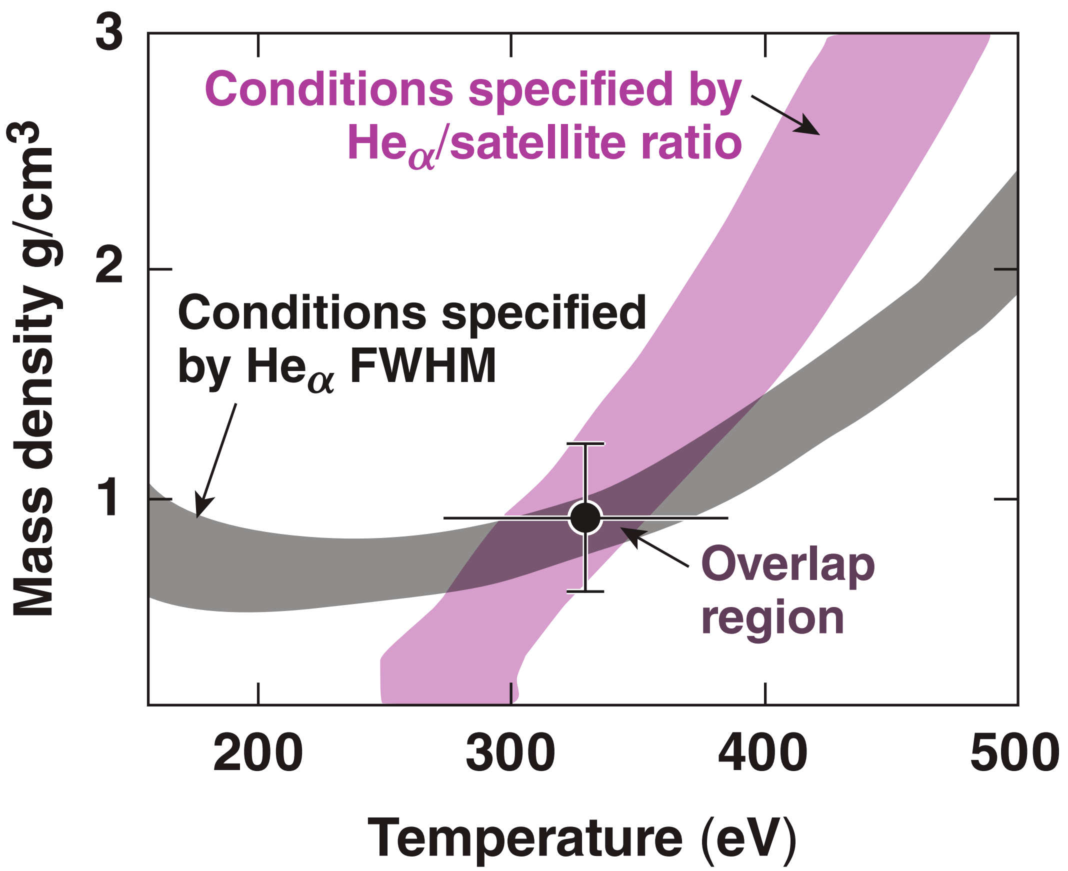
The instantaneous temperature and density were inferred by comparing with a NLTE collisional-radiative atomic physics model*

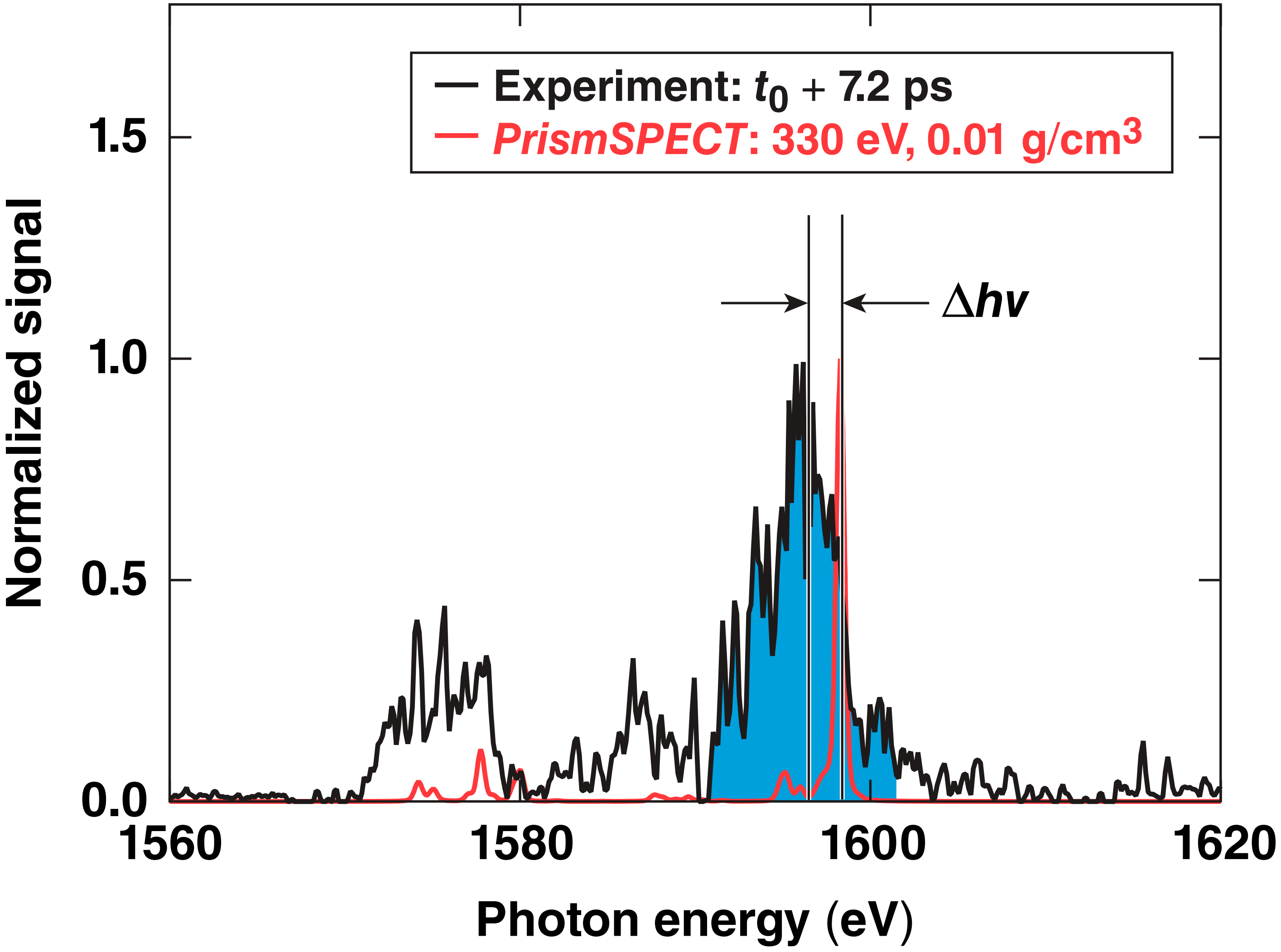




The calculation considers satellite production from Al IX–XIV ions with Doppler, Stark, natural, Auger, and opacity-broadening contributions.

*J. J. MacFarlane *et al.*, High Energy Density Phys. 3, 181 (2007).
**FWHM: full width at half maximum

The spectral shifts were quantified by the first moment of the line shape



A simplified line-shift model based on numerical ion-sphere calculations shows broad agreement with the experimental data

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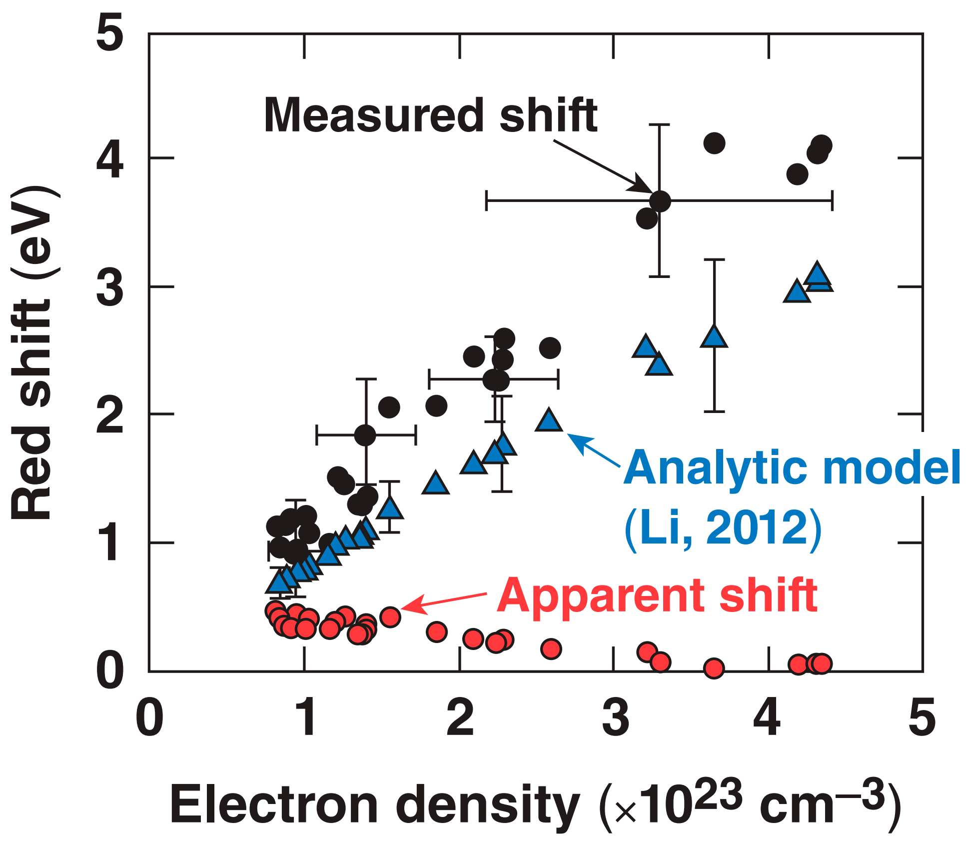

- **The analytic model is a parameterization of the self-consistent ion-sphere model (SCFISM)*,** for dense, finite-temperature plasmas**
- **Apparent shifts calculated from the NLTE atomic model verify that the observed shifts are not spurious**

The line-shift model agrees well at lower densities; there is evidence for deviation at the most extreme conditions.

*F. J. Rogers, H. C. Graboske, and D. J. Harwood, Phys. Rev. A 1, 1577 (1970).
**S. Ichimaru, Rev. Mod. Phys. 54, 1017 (1982).

E25517

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