In-situ hollow ion spectroscopy of strong X-ray fields from ultra-intense laser-solid interactions

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Ultra-intense-laser-solid interactions

Laser-solid interactions at $10^{20}$ W/cm² create an intense X-ray field photo-pumping hollow ions observed in spectroscopy.

X-ray radiation field is thought to originate from:
- Nonlinear laser-electron interactions;
- Relativistic electron transport in solid matter.

We aim to understand the generation mechanisms and spectral properties creating high-energy radiation fields.

Observing highly intense laser interact with a solid

Crystal X-ray spectrometer
Periphery plasma
Crystal X-ray spectrometer

Solid-density plasma

Laser
1054 nm
0.9-3.5 ps
45-352 J

Powerful X-ray radiation fields and hollow ions are observed in experiments at Vulcan Target Area Petawatt using:
- $\approx 10^{20}$ W/cm² laser intensity;
- <10⁻¹⁰ laser contrast – use plasma mirror (PM);
- low-Z and µm-thick targets.

In-situ hollow ion spectroscopy infer the X-ray field

Atomic kinetic modelling to characterise spectra

Atomic kinetic and plasma physics models (like FLYCHK) can provide fundamental understanding of spectral observations.

Spectroscopic measurements are corrected for detection efficiency, crystal reflectivity and filter attenuation for analysis.

Plasma parameters in simple models extend to initial inputs for sophisticated detailed calculations and analysis, addressing:
- diagnostic effects, like spectral resolution;
- missing physics, such as photo-pumping hollow ions.

Interpreting radiation processes from atomic physics

Atomic kinetic modelling link measurements to solid-density laser-plasma kinetic simulations.

EPOCH can model radiation processes that may create high-energy radiation fields.

Aim is to observe effects on electron heating due to:
- laser and material parameters;
- plasma scale-lengths and topographic structure.

Summary

Aim is to understand high-energy radiation mechanisms emerging in ultra-intense laser solid interactions by coupling hollow ion spectra to atomic and plasma models.

Coupled atomic kinetic and plasma modelling will be applied to data evaluation of recent Vulcan petawatt laser experiment.

Atomic kinetic arguments suggest that

$$\frac{I_{\text{x-ray}}}{h\nu} \sigma_{ph} > \Gamma_{a}$$

For Al of energy $h\nu \geq 2$ keV, cross-section $\sigma_{ph} = 5 \times 10^{-20}$ cm² and autoionization rate $\Gamma_{a} \approx 3 \times 10^{14}$ s⁻¹,

$$I_{\text{x-ray}} > 3 \times 10^{16} \text{ W/cm}^2$$

Suggests that induced laser energy to X-ray conversion is 1%. 

Colgan, PRL 110, 125001 (2013); Pikuz, HEDP 9, 560 (2013).