Heat Transport Measurements in Foil Targets Irradiated with Picosecond Timescale Laser Pulses

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Background

• High temperature and high density opacity experiments have been performed on the HELEN CPA laser using short pulse driven electron transport to heat buried layers in plastic foils but the details of the heating mechanism are not understood.

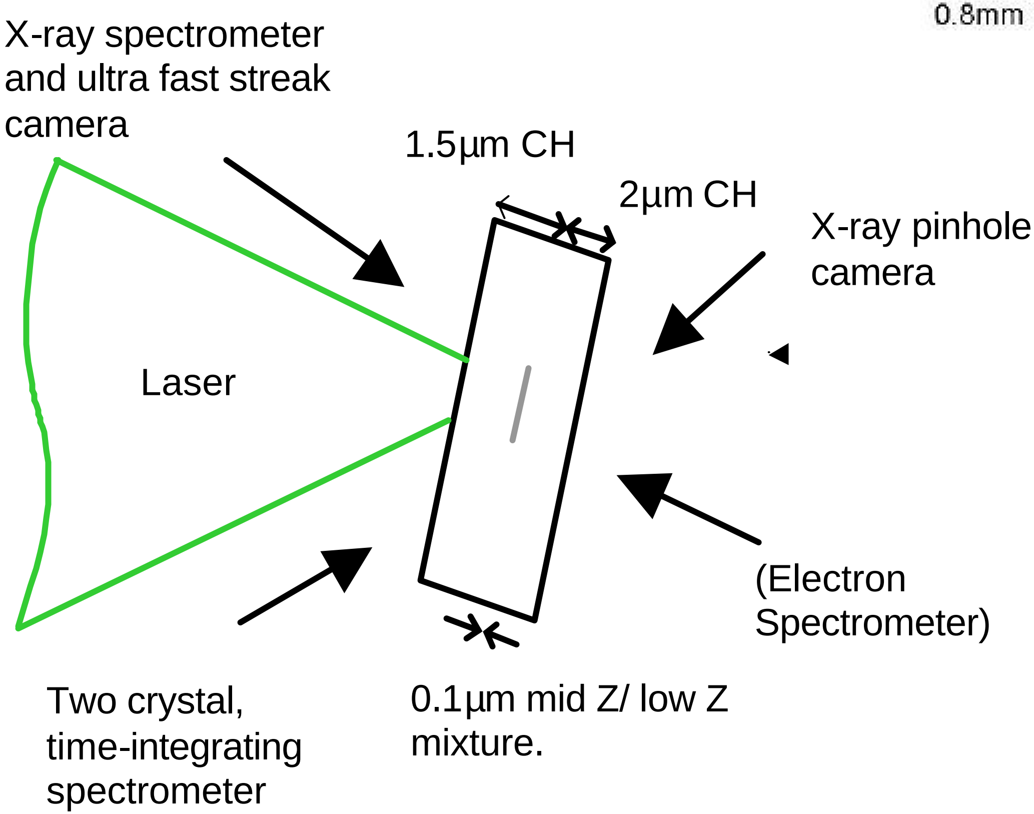
• A number of measurements using X-ray spectroscopy and electron spectrometers have been carried out to try to better understand the heating mechanisms and to benchmark electron transport codes under development at AWE.

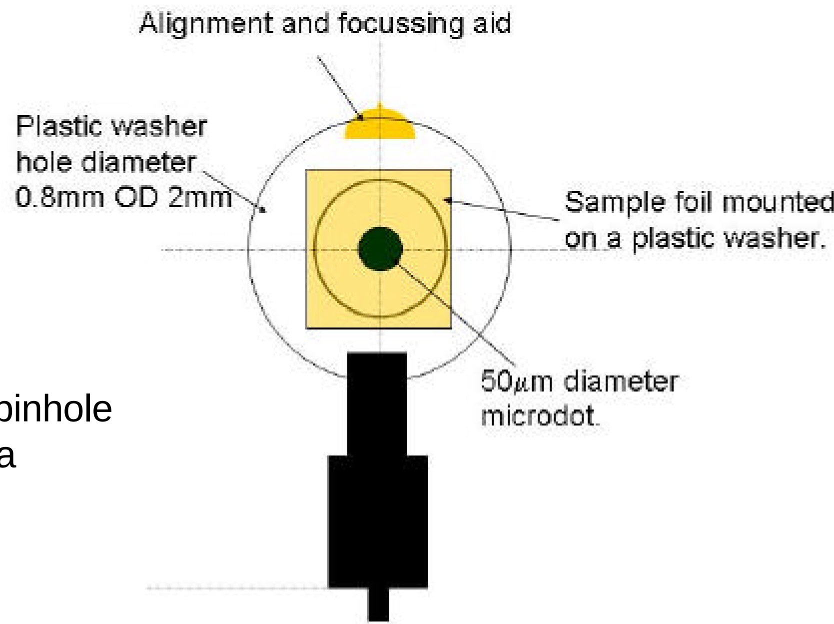
• The time delay of heating at different depths in plastic foils has been investigated using X-ray spectroscopy and an ultra-fast streak camera.

• The effect of target resistivity and refluxing of electrons has been investigated.

Generic experimental diagnostic and target setup

Time resolved and time-integrated diagnostics were fielded.



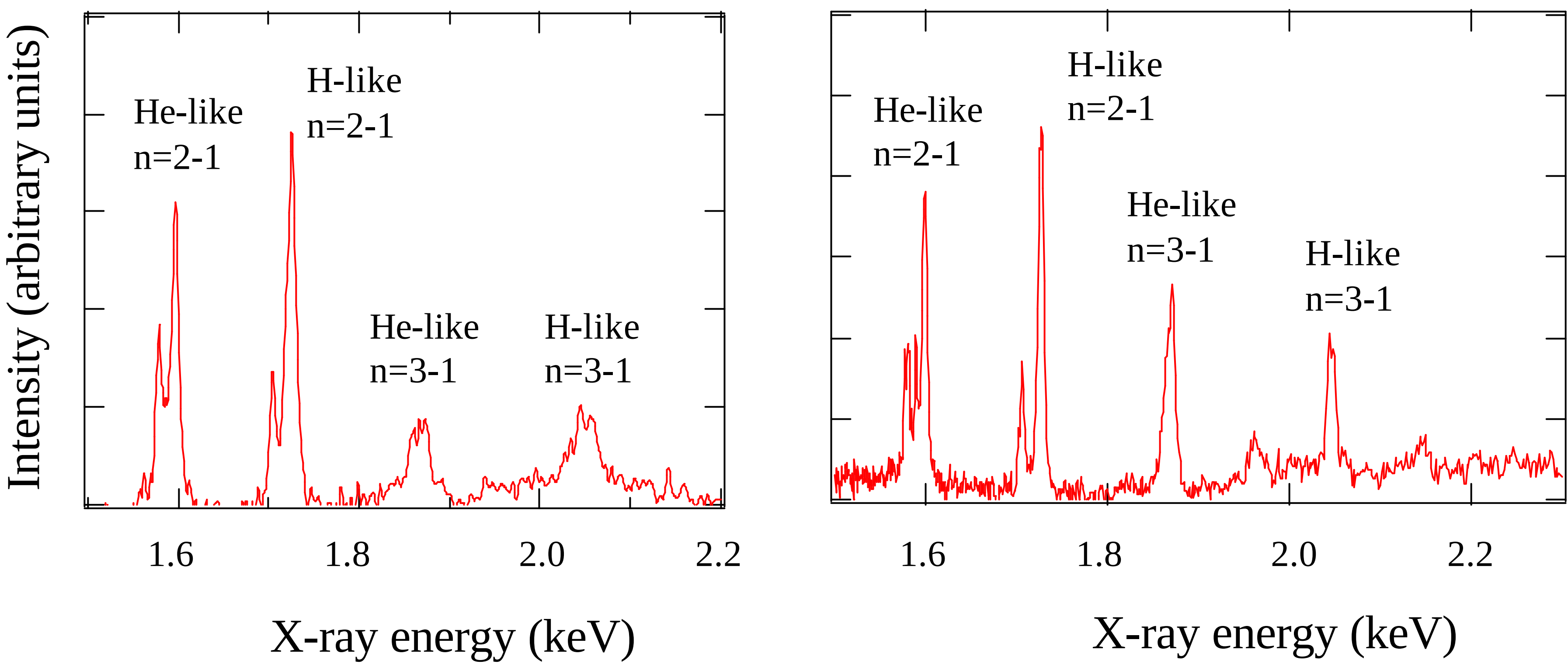


Target mounting

Electron heating of the target not effective in the presence of pre-pulse.

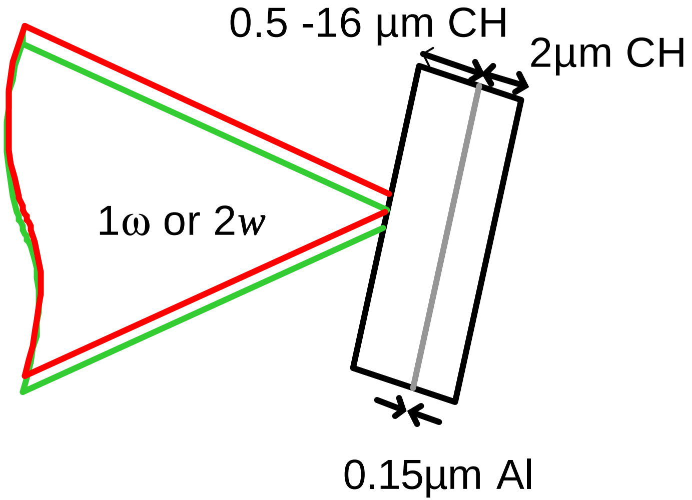
(a) Spectra with green light

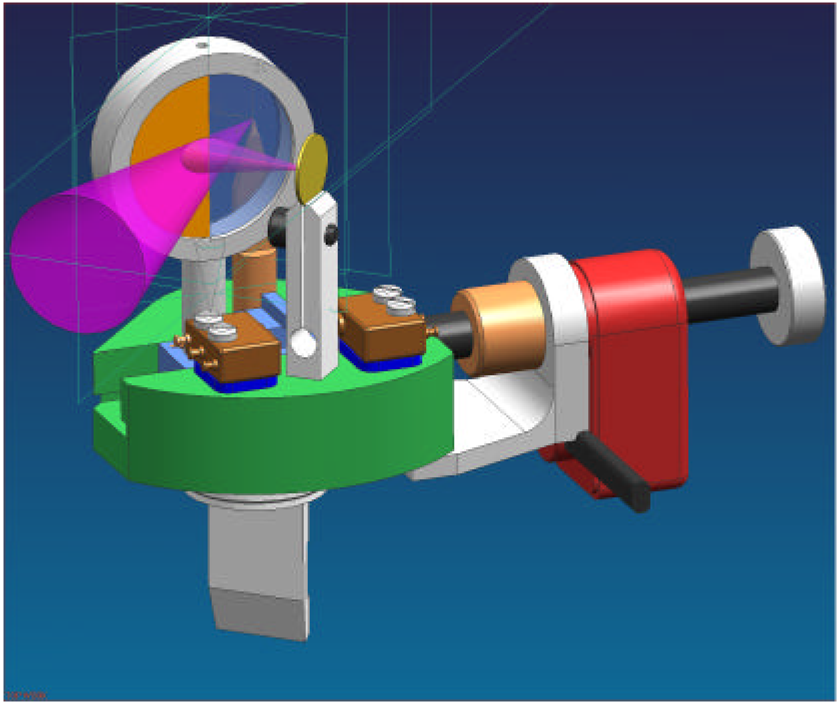
(b) Spectra with infrared light



Pre-pulse mitigation was important for effective heating

2w conversion and plasma mirrors were used to mitigate pre-pulse



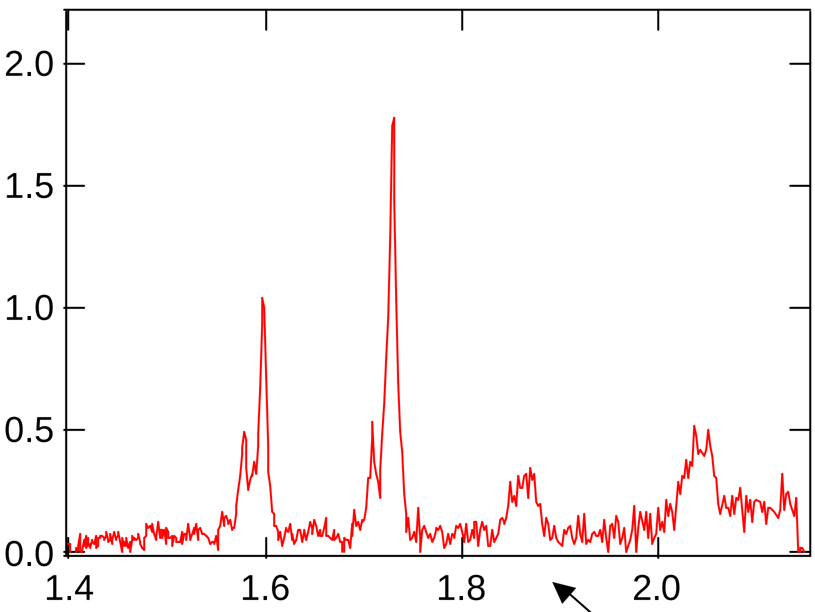


•Plasma mirrors were used in 1.06µm wavelength experiments.

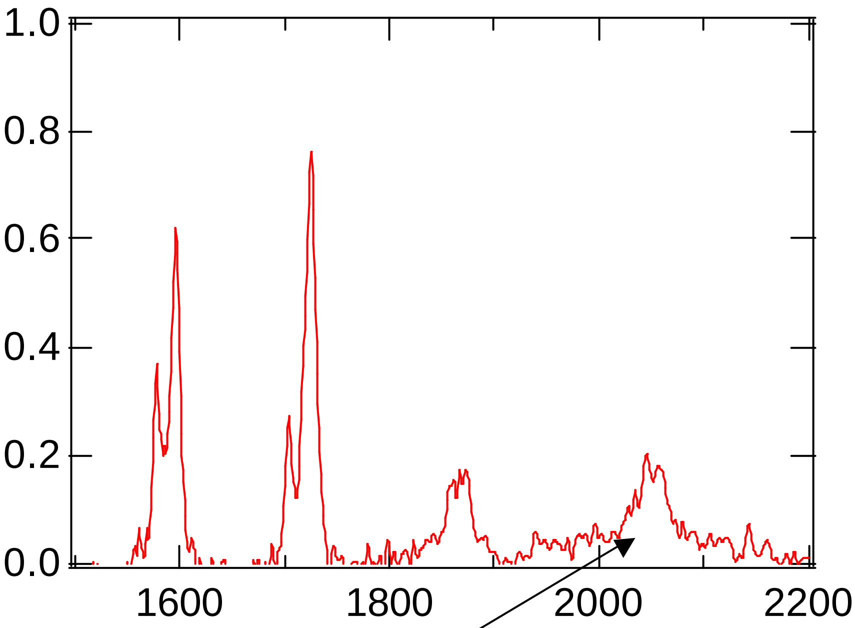
Plasma mirror and 2ω results compared.

IR +plasma mirror produces similar plasma conditions to using green light in experiments with aluminium buried layers

IR+plasma mirror



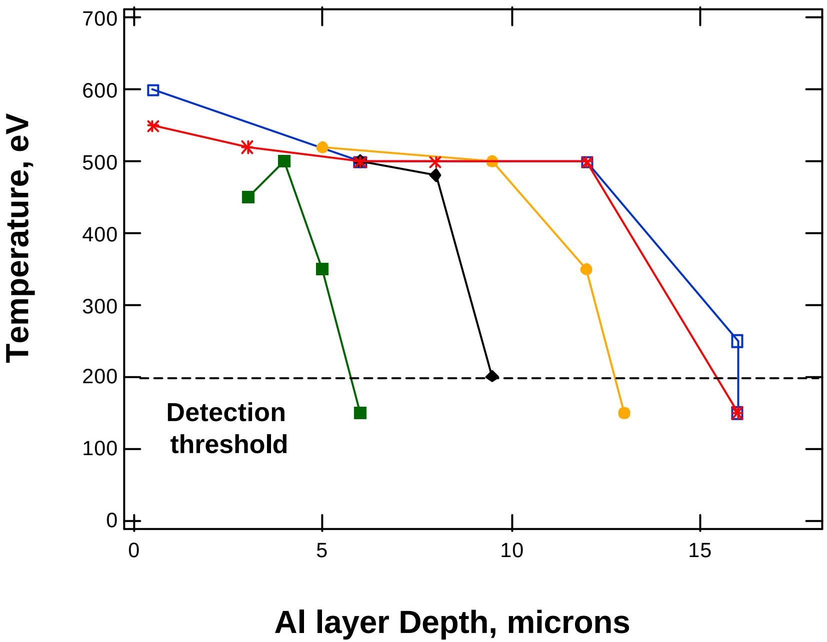
Green light



Broad 1-3 line emission indicates densities ~ 1-2g/cc.
Ly_b/He_b ratio indicates high Te ~500eV

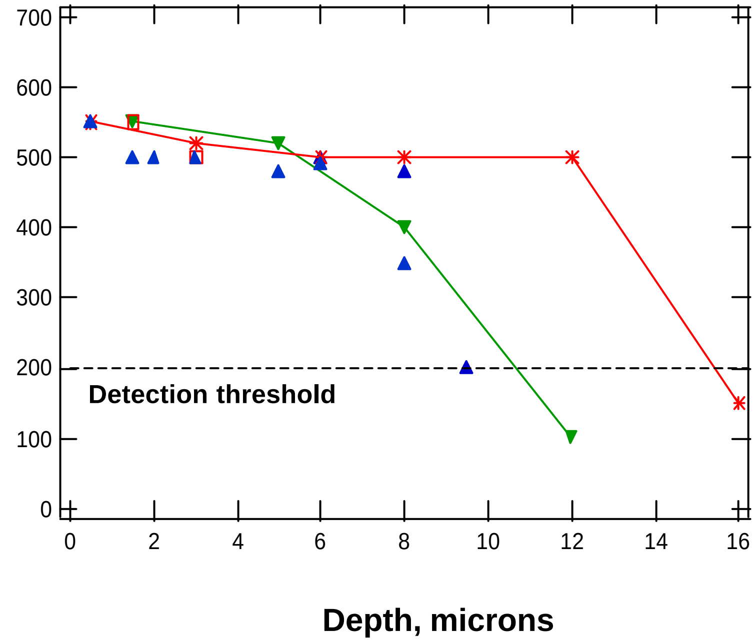
Heat penetration was measured using aluminium layers buried in parylene N plastic foils.

- 10^{19} W/cm^2 P polarisation 2w
- 10^{19} W/cm^2 S polarisation 2w
- 6×10^{17} W/cm^2 P polarisation 2w
- 6×10^{17} W/cm^2 S polarisation 2w
- 5×10^{18} W/cm^2 P polarisation 1w plasma mirror



Penetration with 0.5ps pulses

- 1.6×10^{17} W/cm^2 S polarisation 2w
- 1.6×10^{17} W/cm^2 P polarisation 2w
- 5×10^{18} W/cm^2 S polarisation 2w
- 5×10^{18} W/cm^2 P polarisation 1w plasma mirror

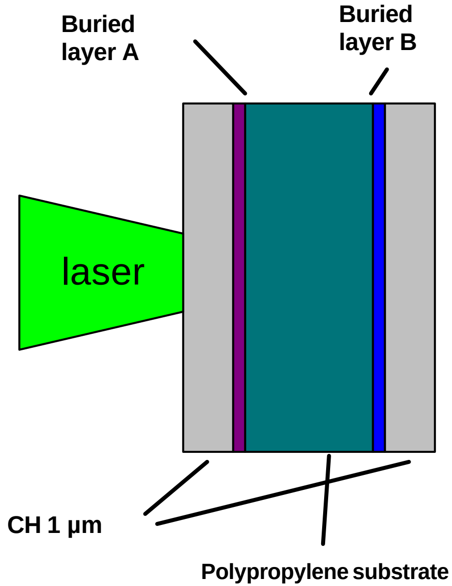


Penetration with 2ps pulses

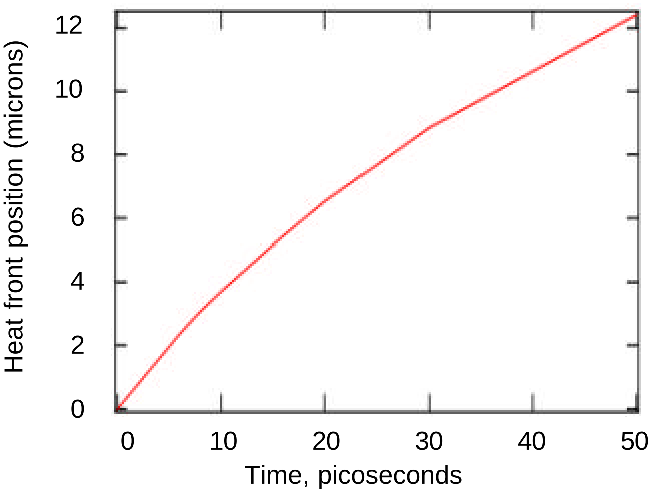
Heating studies using multilayer targets

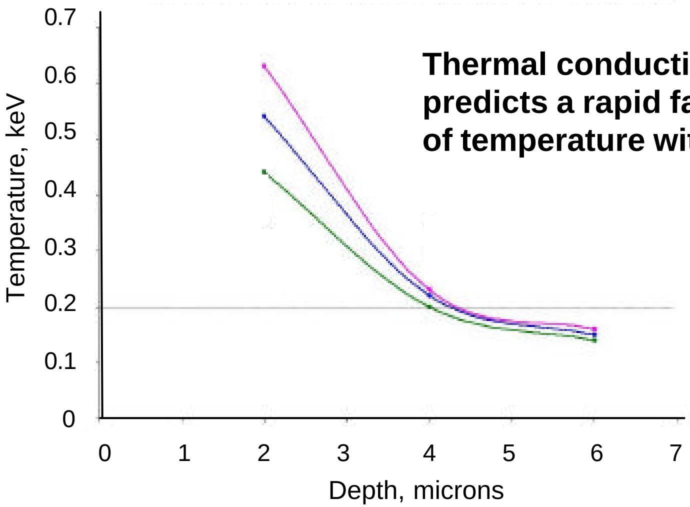
Time delay in the emission of the two layers expected for

- (a) Thermal heat conduction
- (b) Coronal radiative heating enhancing the thermal conduction
- Alternative/ additional heating mechanisms
- (c) Return currents
- (d) electron refluxing



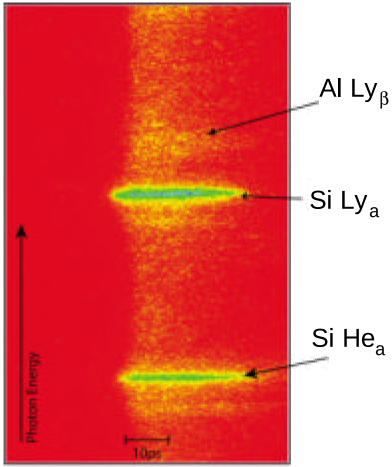
Predicted heat front position v time assuming thermal diffusion of electrons into the target



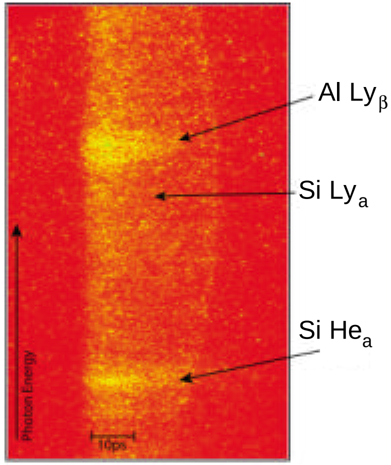


Thermal conduction predicts a rapid fall off of temperature with depth

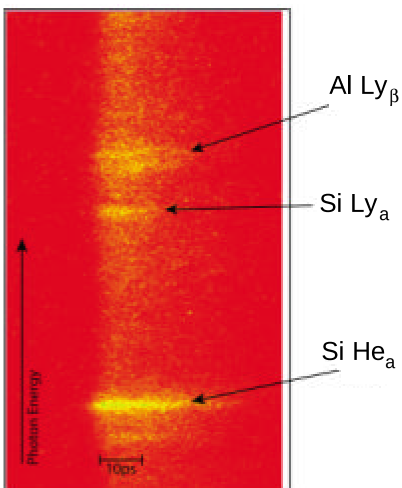
Electron transport experiments with multilayer targets



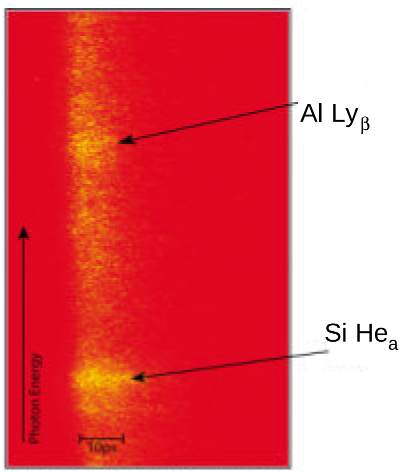
S-pol; 10^{19} W/cm^2; 4µm separation



P-pol; 10^{19} W/cm^2; 15µm separation

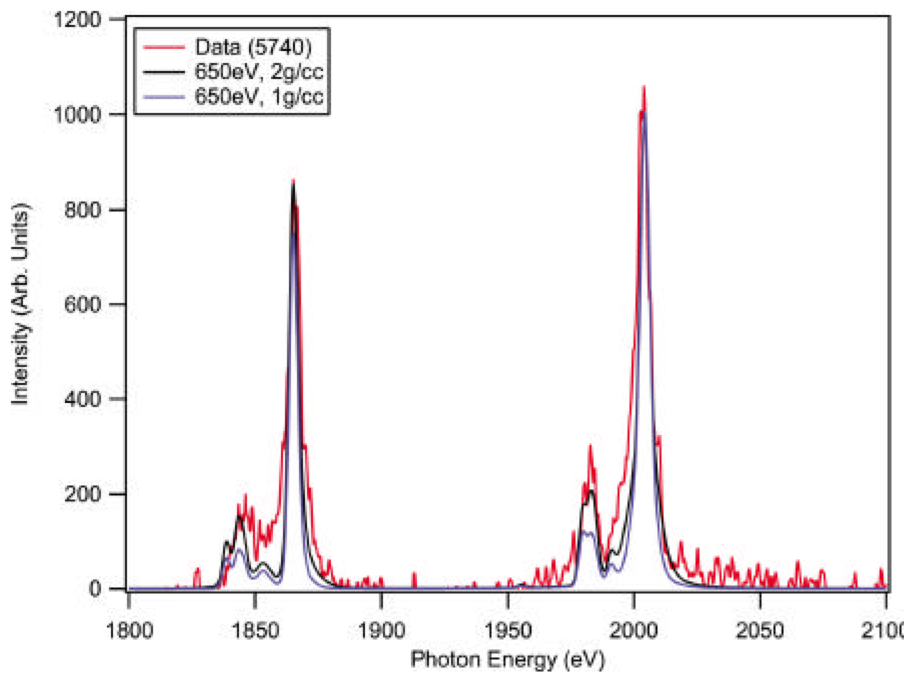


P-pol; 5×10^{17} W/cm^2; 10µm separation



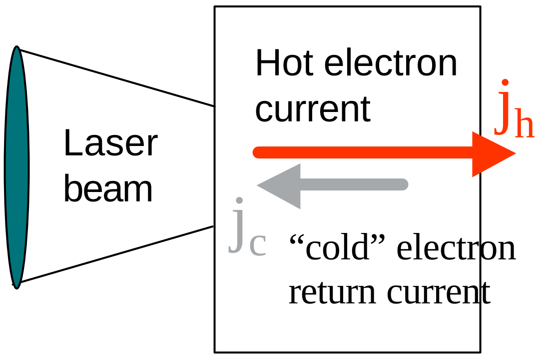
P-pol; 10^{16} W/cm^2; 4µm separation

Temperatures inferred from analysis of the Silicon emission are in reasonable agreement with those inferred from aluminium spectra.



Electron transport models are being developed and will be incorporated into an AWE radiation-hydrodynamics code.

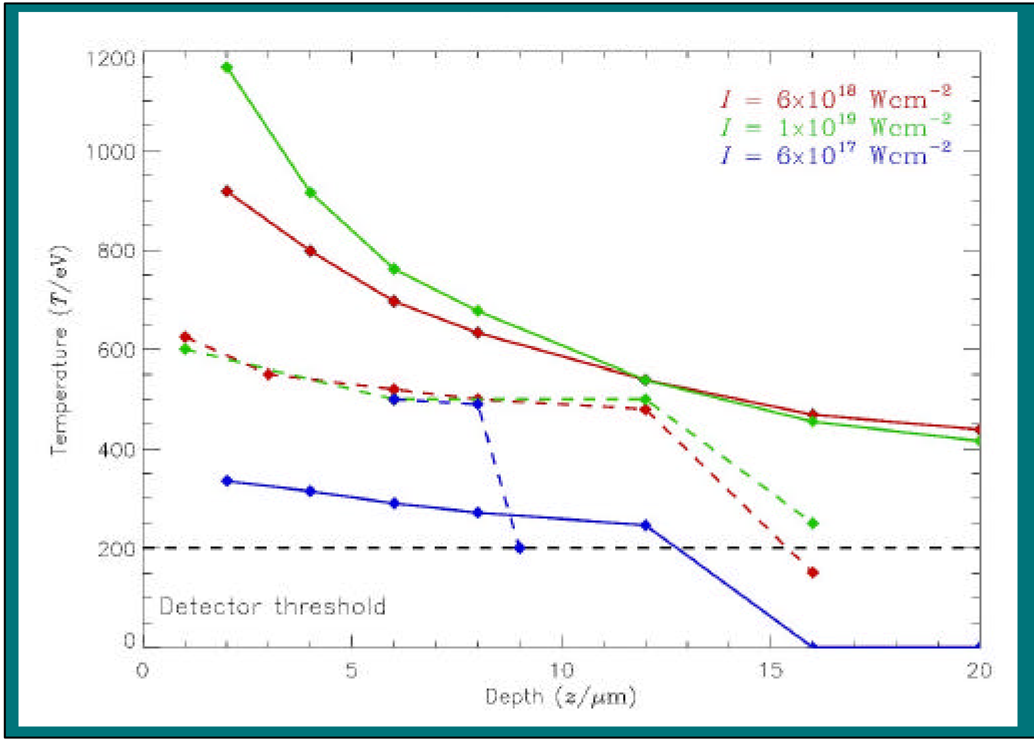
The target heating depends on return currents and the target conductivity σ.



$$j_c = -j_h = s\,.E$$

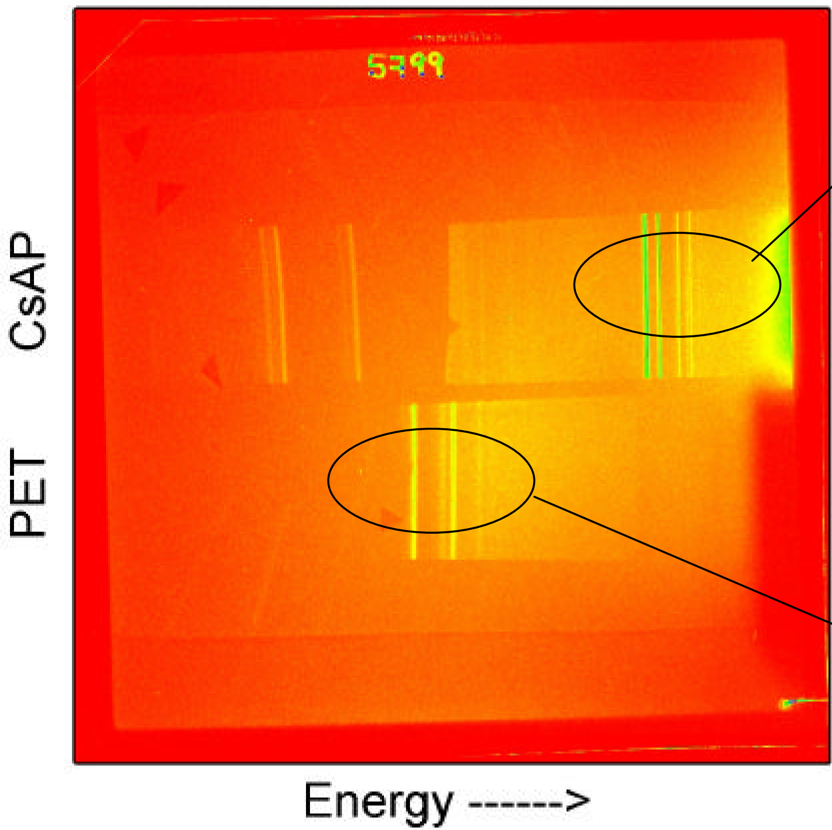
- Thor II electron transport model includes return current heating.

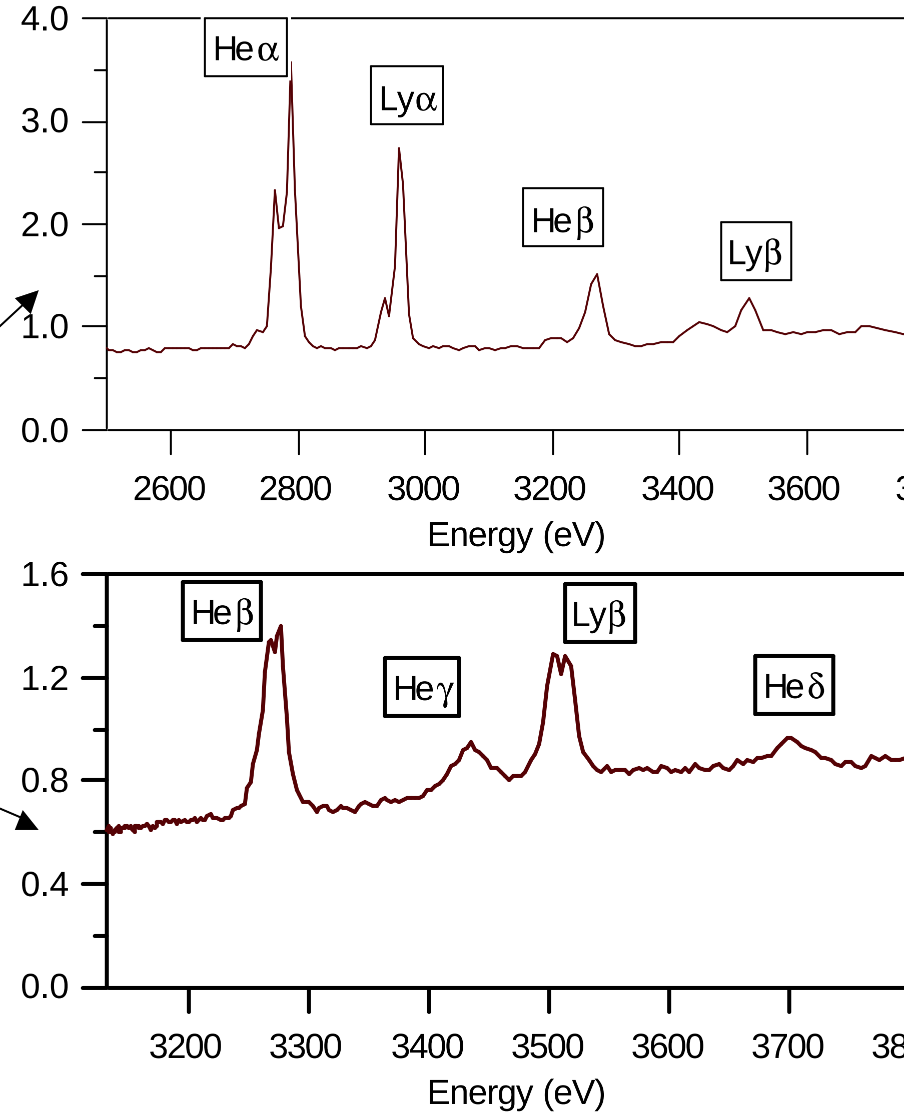
Thor II predictions of target heating v experiment
Dashed lines experiment; solid lines prediction



The effect of conductivity change was studied using chlorinated plastic layer targets.

Target 2µm PyN/1µm PyD/ 2µm PyN
PyD –parylene D 50% by weight chlorine
41J, 0.5ps 2x10[19]W/cm[2].

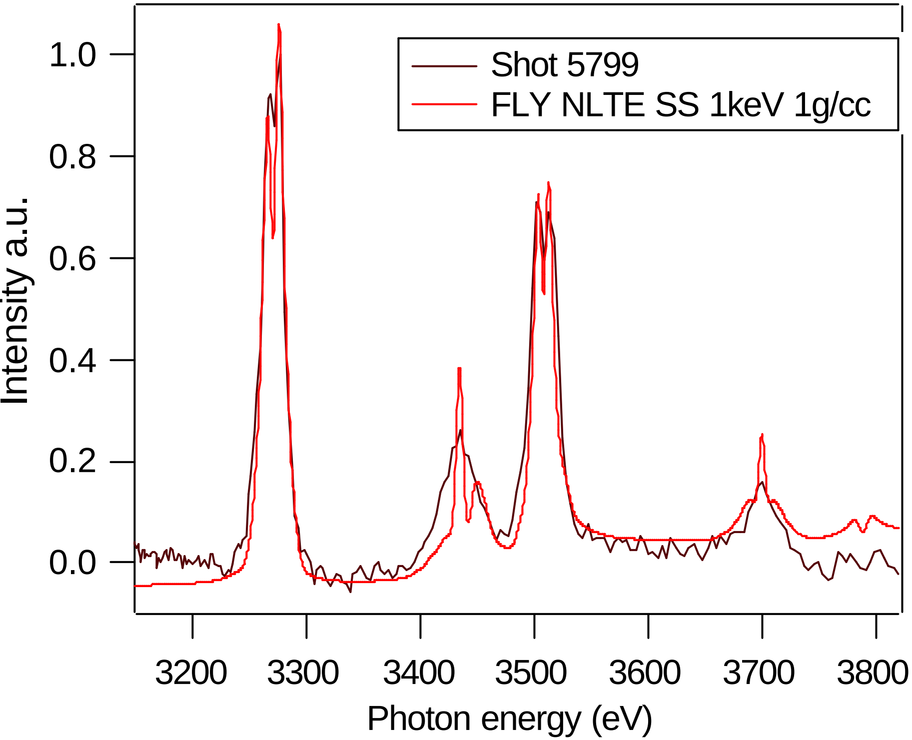




Chlorine 1s3p data indicate higher temperatures than Al, Si.

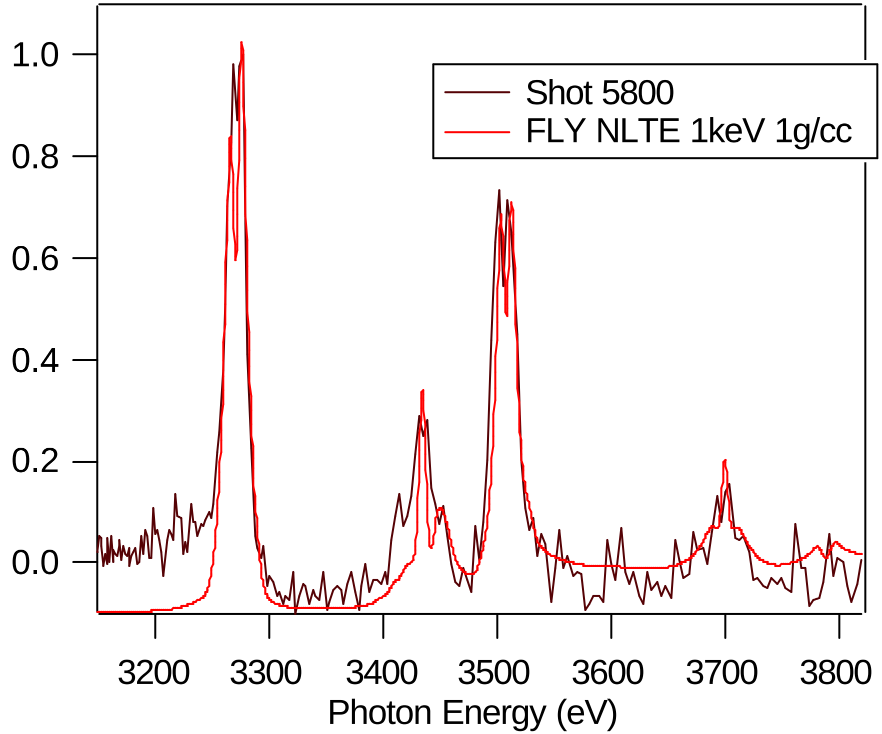
2µm PyN /1µm PyD/ 2µm PyN

41J 0.5ps ~2x10^{19}W/cm^2



6µm PyN /1µm PyD/ 2µm PyN

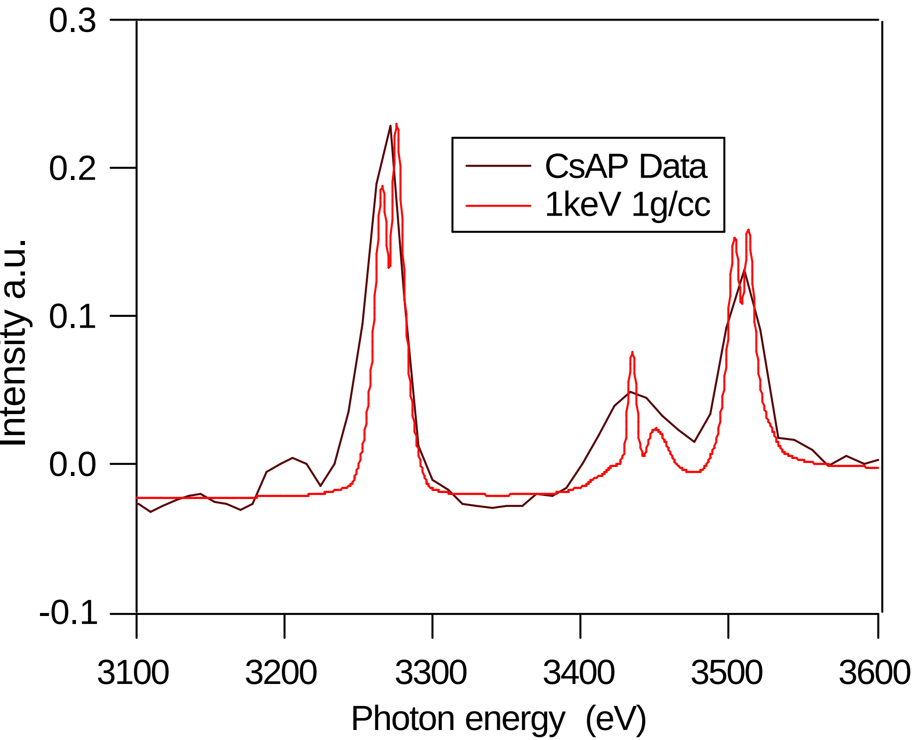
20J 0.5ps ~1x10^{19}W/cm^2

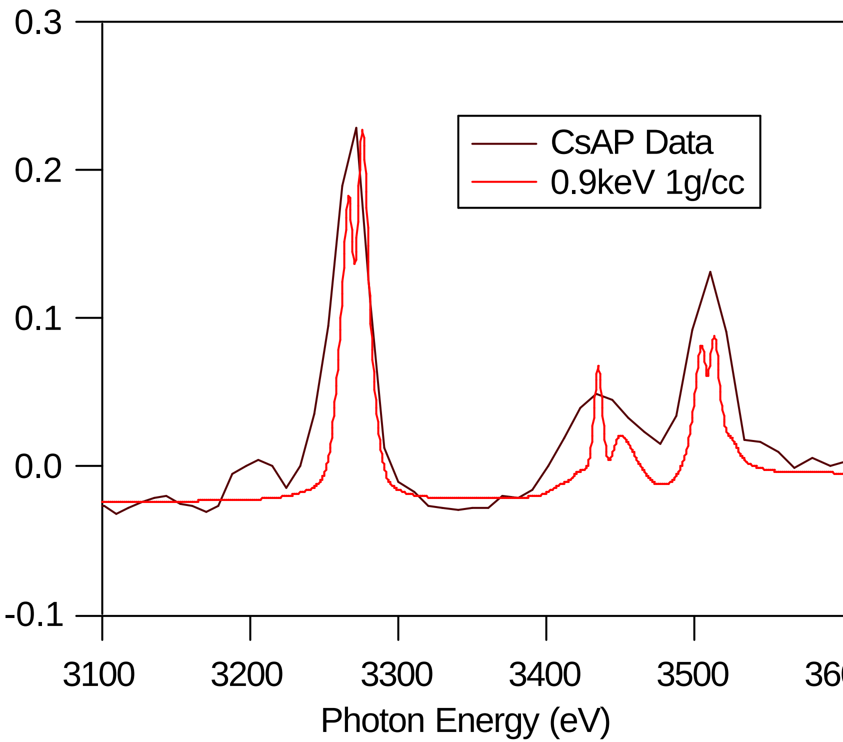


Data is normalised – not an absolute flux comparison.

Low and high spectral resolution data agree.

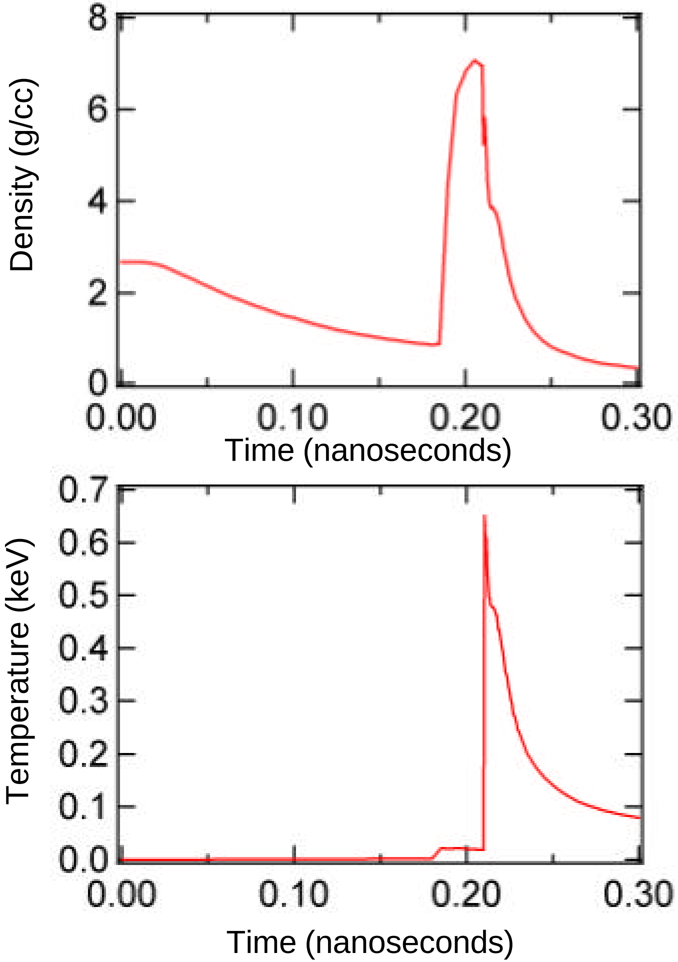
- Although resolution is low (E/dE~300), the temperature inferred from the CsAP crystal spectrum agrees with that from the PET crystal.



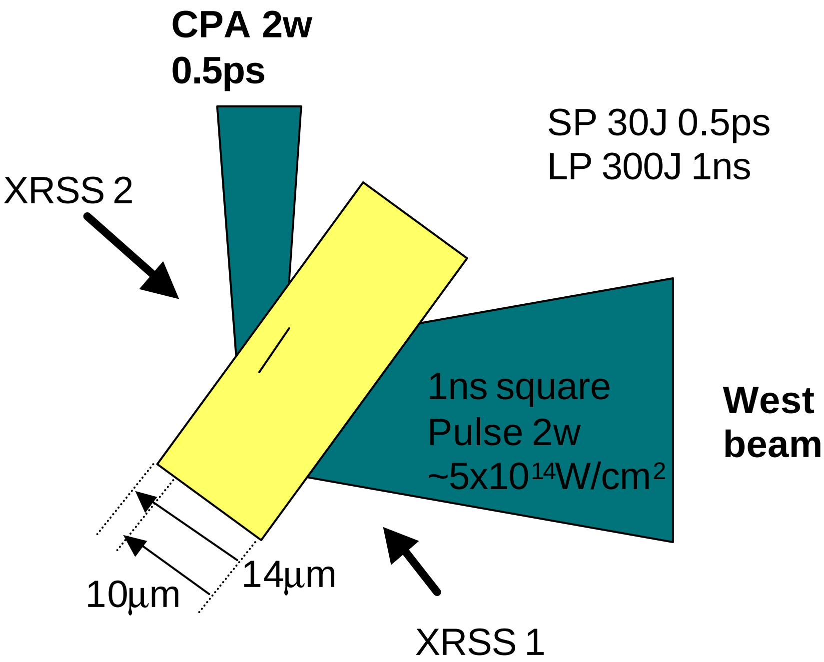


HELEN experiments have demonstrated the technique of long pulse shock compression and short pulse heating.

Predicted density and temperature histories for shock compression and short pulse heating.

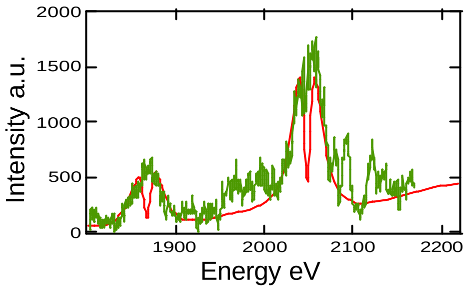


Experimental setup schematic

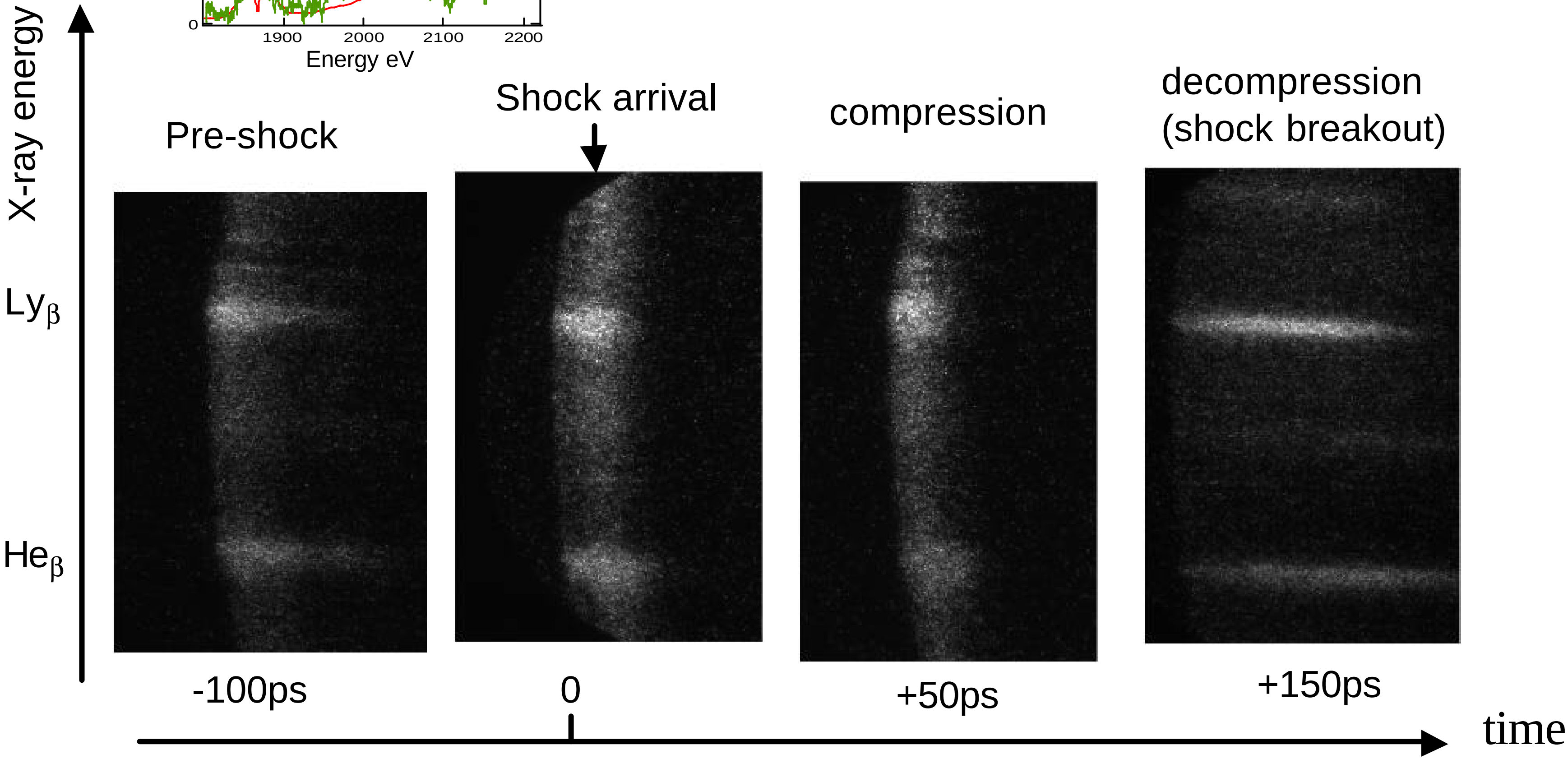


Shock velocity ~3×10^{6} cm/s
Ablation rate ~6×10^{5} cm/s
Ablation pressure ~12Mb

Shocked aluminium experiment streak data – Line broadening used to diagnose shock compression of an aluminium layer.

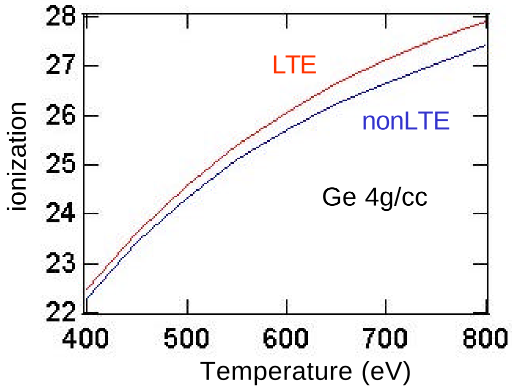


Fits to peak compression indicate density 3g/cc and peak temperature 600 ±50eV.

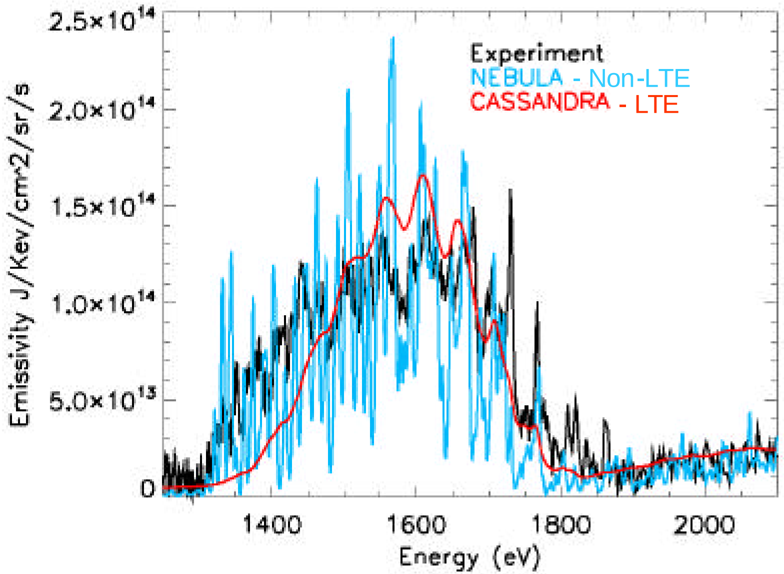


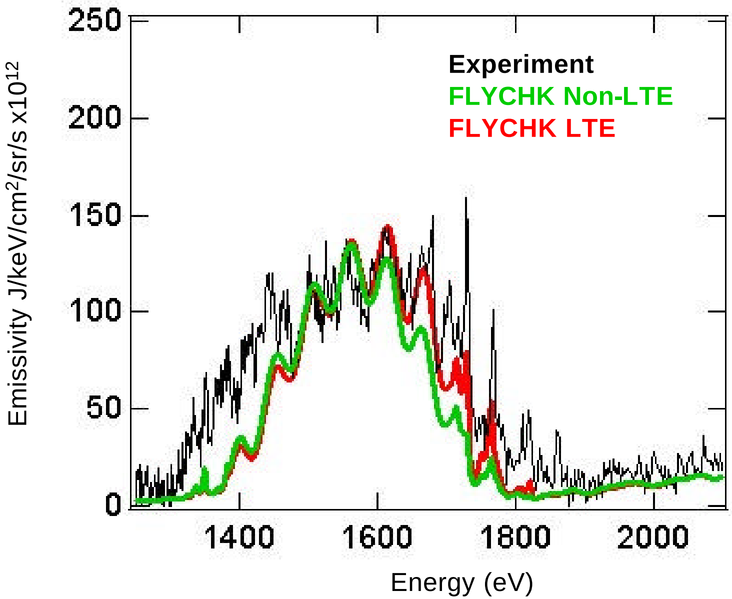
Comparison of LTE and non-LTE opacity code predictions to the shocked germanium data.

The shocked germanium samples are nearer LTE but gradients are an issue.



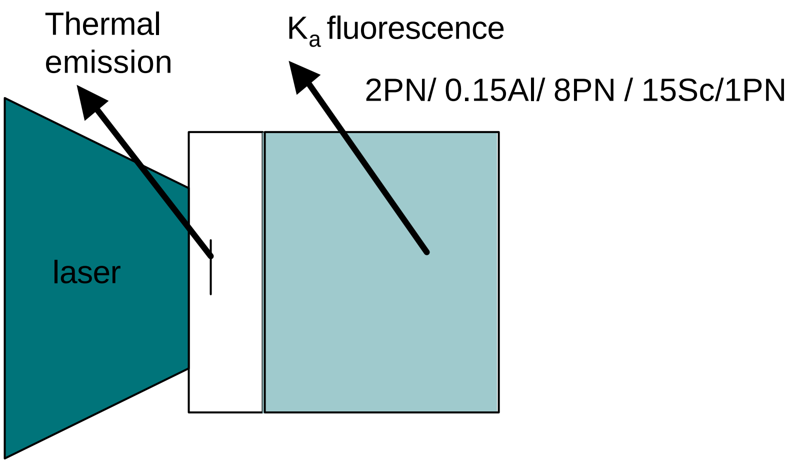
Gradients from radiation-hydrodynamics
450-650eV, 4g/cc

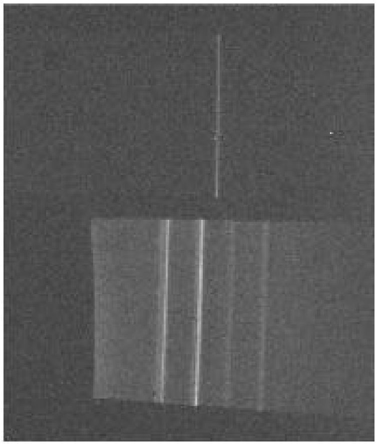




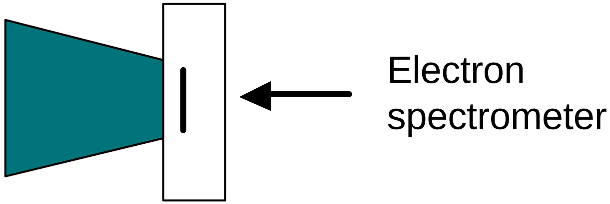
Experiments to measure the electron distribution

Electron distribution inferred from fluorescence

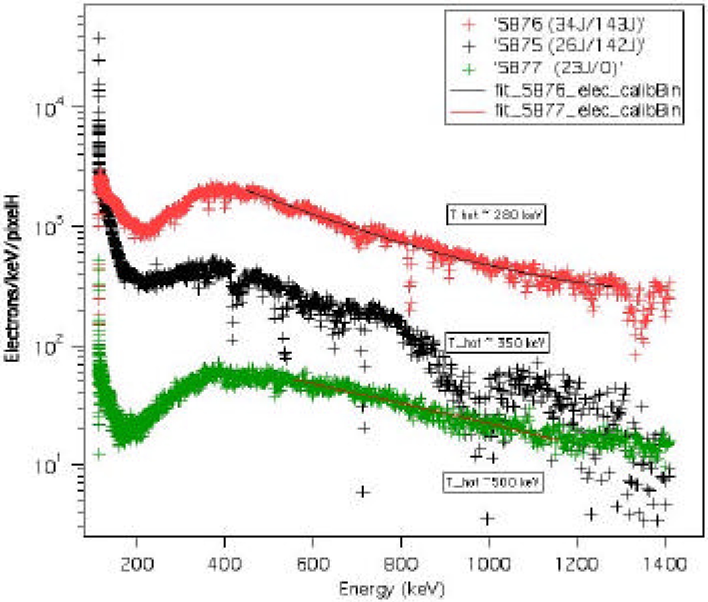




Electron spectrometer measurements



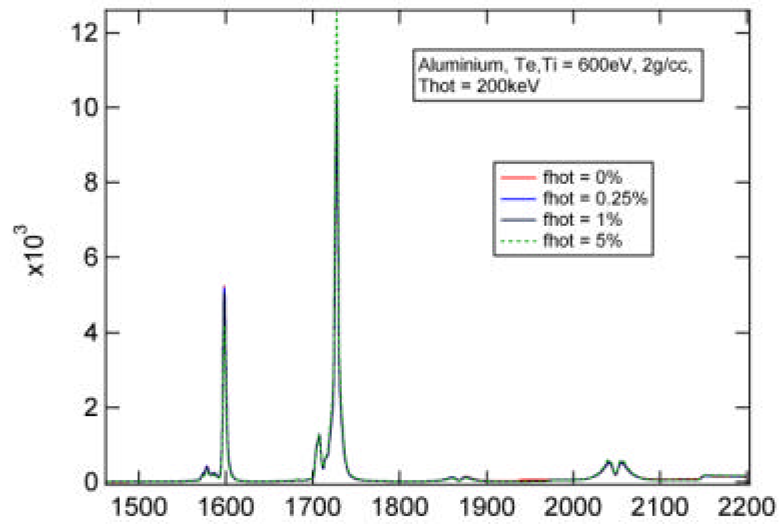
Emergent electron spectra for targets with different density scale-lengths

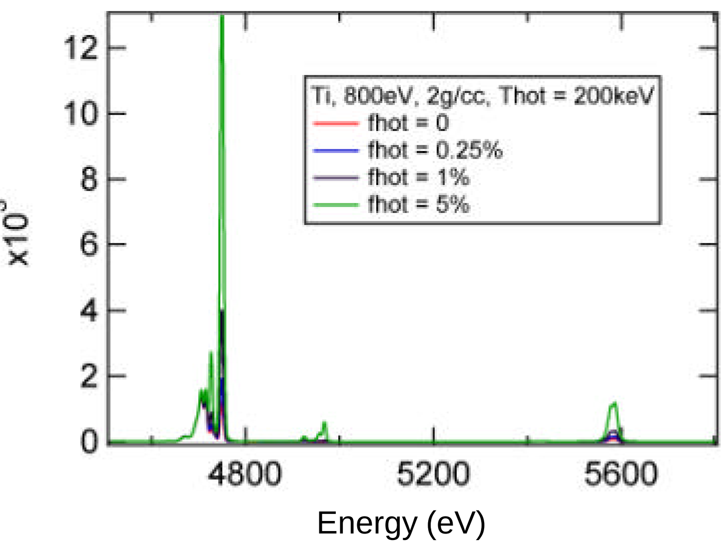


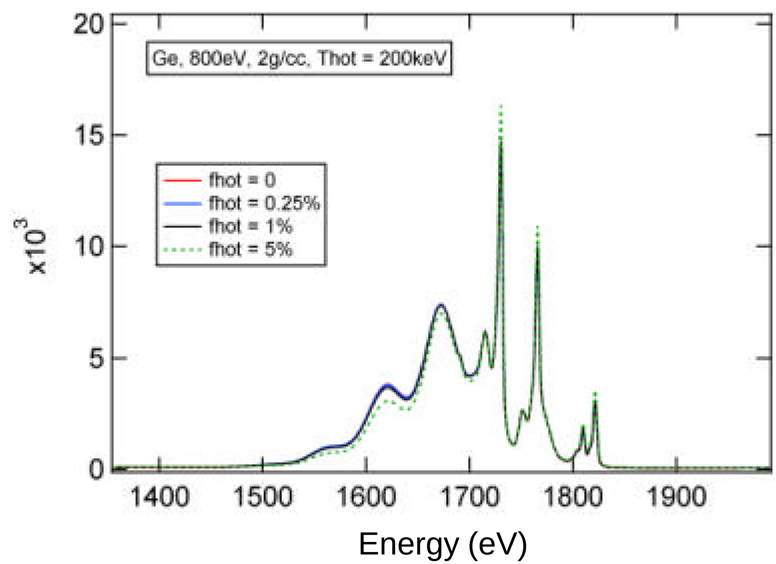
FLYCHK calculations including background hot electrons show these generally have little effect on the spectrum.

$$f_{hot} = \frac{n_{hot}}{n_e}$$

- T_{hot} ~200keV based on Beg scaling.
- HELEN K_a measurements show conversion efficiency 10^{-4} and imply f_{hot} closer to 1% than 5%.
- Possible effect on Ti spectrum. Ly_α/He_β ratio not a good temperature diagnostic.
- Al Ly_β/He_β ratio not affected.







Summary/conclusions

- Electron transport experiments using buried layer targets have shown that target heating using ultra-short pulse lasers is not due to thermal conduction.

- Near instantaneous heating through up to 15µm of plastic is consistent with the Thor2 model of hot electron collisional heating and Ohmic heating via a thermal return current, with Ohmic heating the dominant mechanism.

- Initial experiments changing the target conductivity show an increased heating for insulator rather than metal buried layers.

- Experimental measurements have begun to better characterise the electron distribution in the target.

Future work

- Experiments proposed for the TITAN laser will, if approved, continue this work in the next year. In the longer term studies will continue on ORION.

- It is proposed to better characterise the electron distribution using electron spectrometers and K_α fluorescence and possibly He_α emission.

- It is proposed to investigate further the role of conductivity and to sample deeper buried layers using absorption spectroscopy.