Experiments on the OMEGA EP laser to study scaling of two-plasmon decay instability with plasma conditions

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The two-plasmon decay instability can be detrimental to inertial confinement fusion

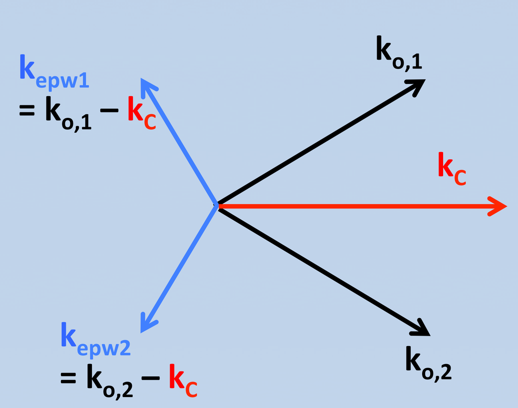
The two-plasmon decay (TPD) instability plays a major role in generating hot electrons (> 10 keV) in long-scale length plasmas.

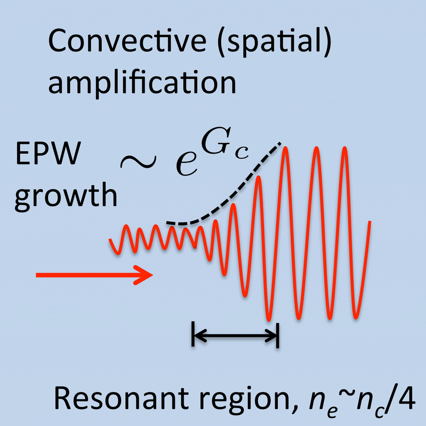
Understanding hot electron production is important to mitigate unwanted target preheat, and high-energy x-rays that interfere with diagnostics.

We performed experiments on the OMEGA EP laser to study how TPD scales over a wide range of plasma conditions. It is seen that hot electron fraction and temperature decrease with plasma Z, thought to be a result of combined hydrodynamic and collisional effects.

Growth of TPD is limited by plasma hydrodynamics and collisionality, which depend on Z

Multiple laser beams can drive resonant, or "common" electron plasma waves (EPWs) with gains much larger than those for a single beam [1]. The EPWs' energy is transferred to hot electrons via Landau damping.





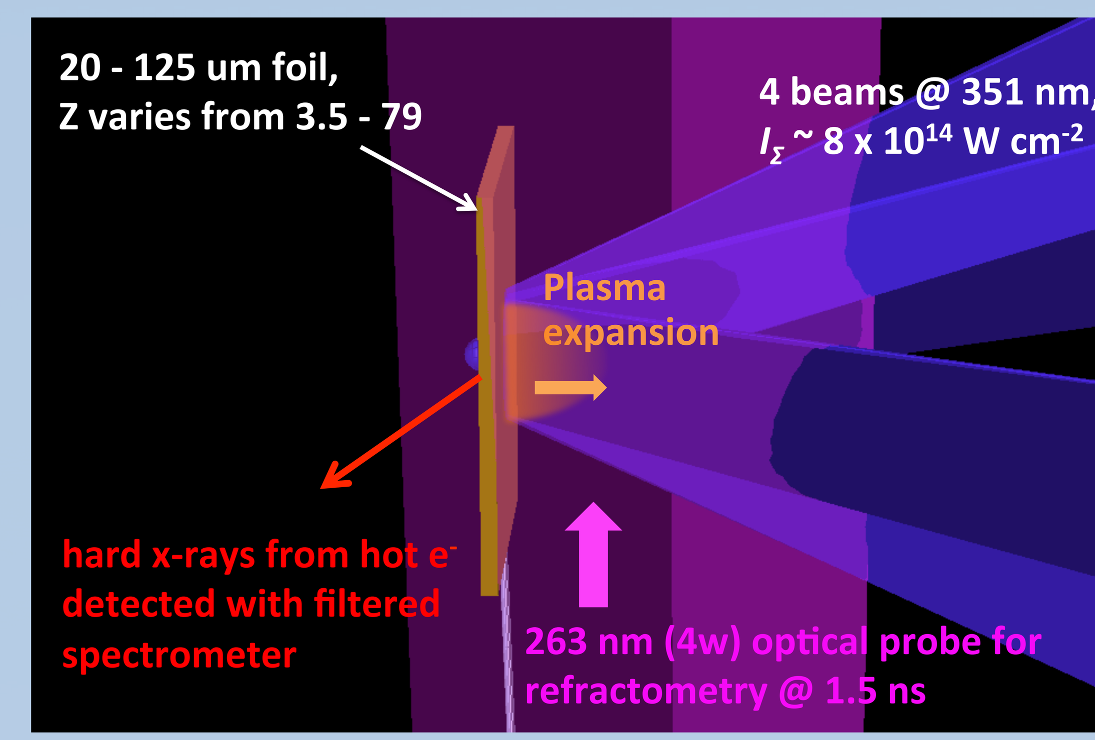
$$G_c \propto \left.\frac{I_\Sigma L_n}{T_e}\right|_{N_{qc}}$$

I_Σ : Total overlapped intensity

Higher Z leads to:

- more collisional damping (v_{ei}) of EPWs before their energy is transferred to hot electrons
- increased laser absorption, I_L reduced at N_{qc}
- slower expansion, shorter density scale length, L_n at N_{qc}
- Lower threshold for nonlinear saturation [2]

We performed experiments spanning a variety of hydro and collisional conditions for TPD



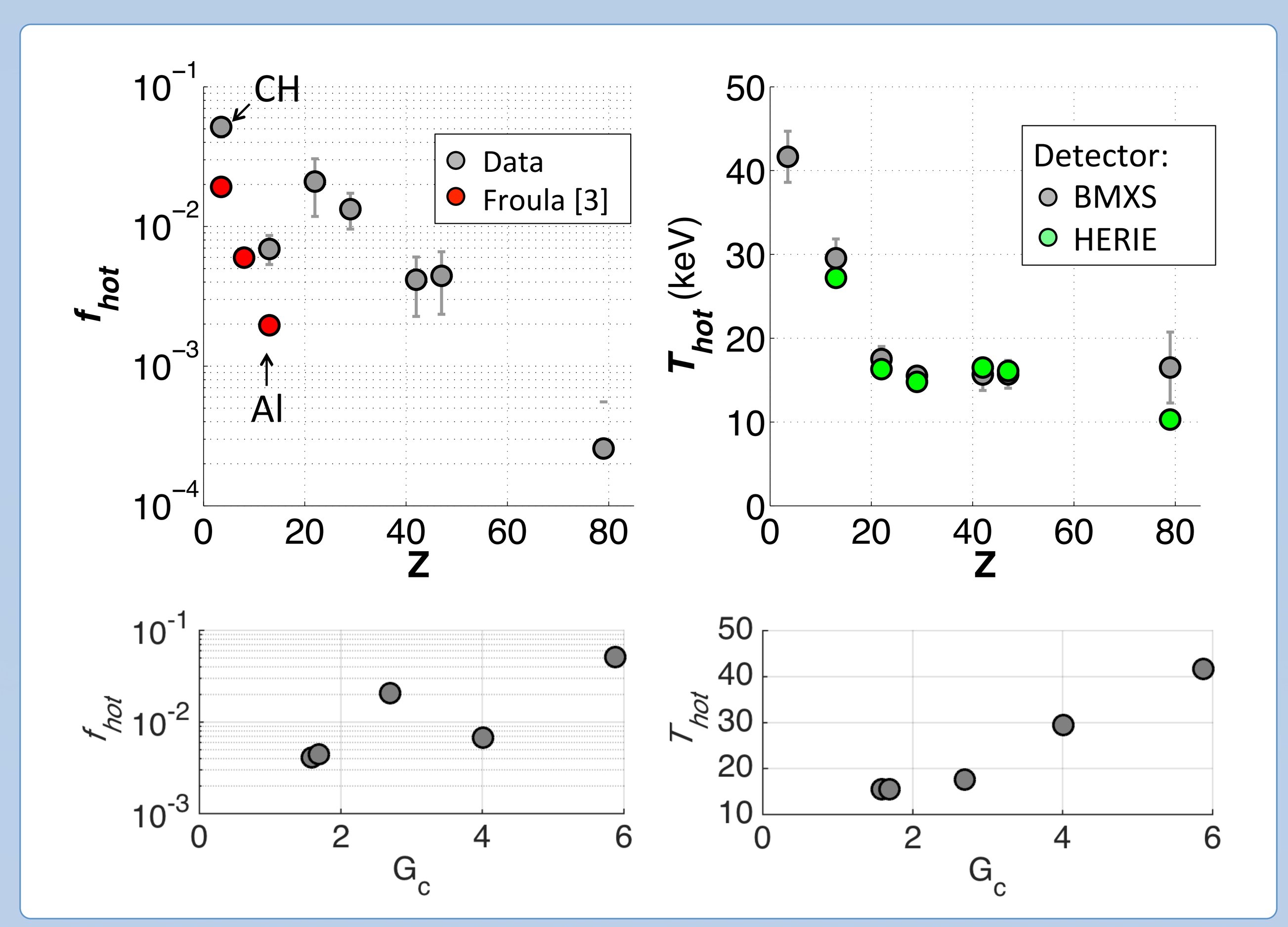
Chosen target materials span a wide range of (Z): CH (3.5), Al (13), Ti(22), Cu(29), Mo(42), Ag(47), Au(79)

Hard x-ray measurements indicate that hot electron fraction and temperature decrease as the plasma Z increases

A bremsstrahlung x-ray spectrometer measures the hard x-rays produced by the interaction of TPD-generated hot electrons in the target.

Hot electron fraction, f_{hot} and temperature, T_{hot} estimated using brems. thick-target model for Maxwellian electrons:

X-ray spectrum: $$\frac{dN}{dE} = \frac{C f_{hot} Z}{E} e^{-E/T_{hot}}$$



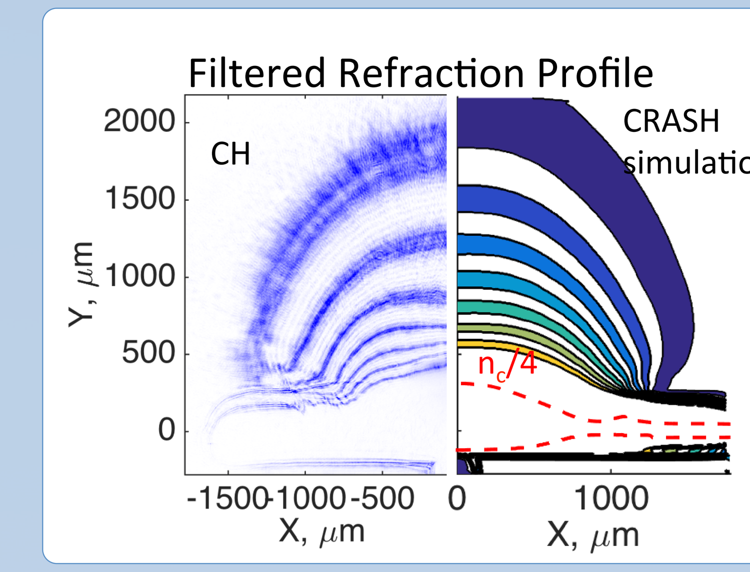
The fraction of hot electrons and temperature clearly decrease as a function of plasma Z., and scale with estimated TPD gain. This is consistent with previous results.

Electron density scale-lengths, L_n are estimated from optical probe measurements, to be used in TPD simulations

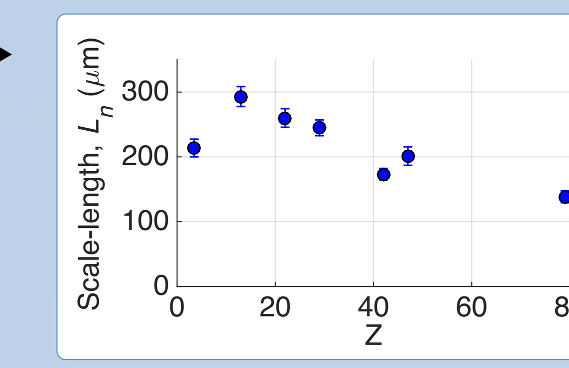
AFR images electron density profiles, n_e, by mapping refraction of probe beam through plasma to contours of constant (known) refraction angle in the image plane [4].

Refraction angle relates to n_e via:

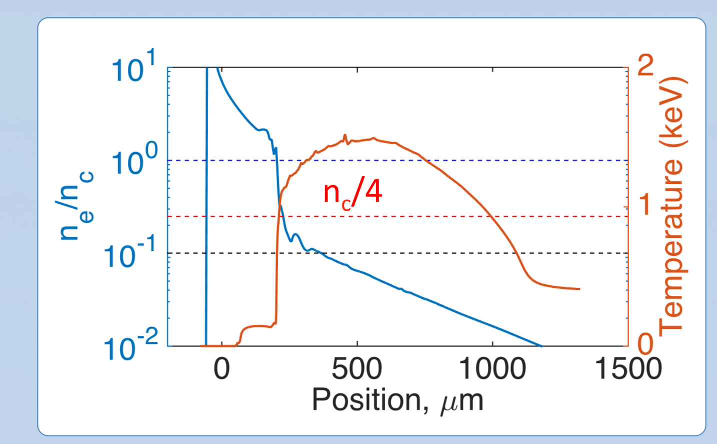
$$\theta_{tot}(x,y) = \frac{1}{2n_c}\left|\nabla_{x,y}\int_{-\infty}^{\infty} n_e dz\right|$$



Estimates of L_n using simple model, shows steepening with increased ion mass



CRASH [5] radiation-hydrodynamic simulations show reasonable agreement with data for low-to-mid-Z targets, but for hi-Z materials large variations in L_n above $n_c/10$



Complex dynamics near quarter-critical lead to uncertainties in estimates of L_n

L_n and corresponding plasma parameters from rad-hydro sims. and modeling are used to calculate TPD gain and later as initial conditions for TPD simulations to estimate f_{hot} and T_{hot}.

TPD simulations can help describe which mechanisms are most important to mitigate TPD

Conclusions and future work

Hot electron fraction and temperature decrease with plasma Z, indicating that TPD growth is strongly affected by plasma conditions.

Measured electron density scale-lengths generally decrease with increasing ion mass. This is consistent with the scaling of hot electron production through the common-wave gain model.

Improved modeling of plasma corona will enable estimation of density scale-lengths at quarter critical, which will be used as initial conditions for future TPD simulations.

Simulations of TPD will be performed with LPSE code to calculate hot electron fraction and temperature, which can be compared to our experimental results.

References and acknowledgements

References:

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