A Model of Hot-Electron Signals with Overlapping Pump Beams

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Summary

• Experiments have shown an unusually strong variation of the hot electron signal with the number of overlapped beams.

• We propose a phenomenological model of explanation.

• The model also predicts the signal variation with energy in a single beam, and this is in accord with experiment.

• The predicted effect of SSD or PS on the signal is in qualitative accord with the observations.
There are some intriguing aspects to the hard x-ray signals in certain OMEGA experiments

- At the 2001 Anomalous Absorption Conference, Stoeckl showed that these signals are clearly correlated with electrons arising from the two-plasmon instability.

- The original set of experiments, in spherical geometry, showed that the signal increased sharply with overlapped intensity (which varied with the target diameter).

- Later planar-foil experiments, using up to six interaction beams, clarified details of the variation.
Hard x rays and $3\omega/2$ signals correlate in time and intensity ($2\omega_p$ instability)
The hard x-ray signal increases exponentially with the number of overlapped beams

- The contrast between an expected linear variation with the number of beams and the measurements is striking.

- Simultaneous and coherent action of several lasers’ electric fields, at quarter-critical, is one possible explanation but seems highly unlikely.

- Instead, we would like to propose a phenomenological model.
The model is based on a few assumptions

1. The signal is from hot electrons produced by the two-plasmon instability near quarter-critical. The single-beam signal may be represented in the form

\[ S_1 = \alpha P_{\text{noise}} G, \]

where \( G \) is the gain in the two-plasmon wave power over the thermal level \( (P_{\text{noise}}) \) and \( \alpha \) represents the conversion efficiency to x rays.

2. The gain is over a very brief time interval (in a hot spot or filament), owing to pump decorrelation induced by the dynamical plasma. A possible time interval is of the order of sub-picoseconds (Vu, LULI).

3. With two similar beams, the enhanced plasma-wave bundle enters, or is overlapped by, a feature in the second beam, and further growth occurs. The signal increases to

\[ S_2 = \alpha P_{\text{noise}} G^2. \]
4. We assume no correlation between the two beams, as regards their initiation and development of the instability.

5. For \( N \) similar overlapped beams, each contributes in a statistical fashion. The resultant signal is

\[
S_N = \alpha P_{\text{noise}} G^N;
\]

or

\[
\ln S_N = N \ln G + \ln (\alpha P_{\text{noise}}),
\]

which fits the experimental results. Of course, the linear variation of \( \ln S_N \) with \( N \) must turn over when nonlinear effects limit further plasma-wave growth.

- A rough comparison with the data yields \( G \cong 5 \)
Let us apply this model to experiments with reduced energy in the beams

- Stoeckl has compared different numbers of beams with reduced energy. He finds a common trend.

- For example, he finds that six beams at half-energy yield the same signal as three beams at full energy. Using our model, this requires

\[ \alpha P_{\text{noise}} G_{\text{half}}^6 = \alpha P_{\text{noise}} G_{\text{full}}^3 \]

or \[ G_{\text{half}} = G_{\text{full}}^{1/2} \].

- Further, a similar equality is seen for equal divisions of the total energy among N-beams. This implies

\[ \alpha P_{\text{noise}} (G_N)^N = \text{cst}, \]

where \( N = \frac{E}{E_N} \).
Let us apply this model to experiments with reduced energy in the beams (continued)

• Hence,

\[ N \ln (G_N) = \text{cst.} \]

or

\[ \ln (G_N) = \beta E_N \]

or

\[ G_N \sim \exp (\beta E_N). \]

• This exponential dependence of the single-beam gain on energy has been verified by experiment.
The x-ray signal rises exponentially with laser intensity

- 20-µm shell, 1-mm-diam, 1-ns square

Signal = \(0.32 \times e^{0.8 \times I_{14}}\)
Here are some comments on collisional effects, SSD, and polarization smoothing

- SSD would increase the probability of hot-spot features moving across the enhanced packet of waves; hence, the signal would increase with SSD.

- PS would mostly decrease the intensity in each hot spot, thus decreasing the signal.

- Both of these tendencies have been seen.
Improvements in the single-beam nonuniformity by SSD or PS affect the hard x-ray emission for spherical targets

- CH shell, 950-μm diam., 1-ns square, varying single-beam intensity

![Graph showing signal vs. overlapped intensity with data points for SSD on, no PS, SSD on, PS, and SSD off, PS, and a fit line with the equation Signal = 0.013 × exp (I_{14}/1.19).]
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