**Plasma Physics and Broadband Lasers—A Path to an Expanded Inertial Confinement Fusion Design Space**

**Technical challenges**

- Reduced beam diameter ($D/D_0 < 0.1\%$)
- Wavelength detuning ($\Delta \lambda/\lambda_0 \sim 1\%$)
- Multicolor beams ($1\omega/2\omega/3\omega$)
- High-power achromatic lenses
- Three-color OMEGA
- Stimulated rotational Raman scattering (end of system)
- Bandwidth (spectral lines) ($\Delta \omega/\omega_0 > 10\%$)
- White-light laser (WL-OPA)

**LPI mitigation**

- Current ICF laser drivers
- Spatial mitigation (phase plates)

**Capabilities**

- Bandwidth
- Wavelength detuning
- Multicolor beams

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**48th Anomalous Absorption Conference**
Bar Harbor, ME
8–13 July 2018
Summary

Laser–plasma instabilities (LPI’s) set the design space for all three approaches to inertial confinement fusion (ICF)

- Mitigation of cross-beam energy transfer (CBET) on OMEGA is the largest lever for improved hot-spot pressures on OMEGA, but will also require control of hot-electron production.
- Modeling suggests that beam-to-beam wavelength shifts ($\Delta \lambda \sim 1 \text{ nm}$) could mitigate both CBET and hot-electron generation on OMEGA.
- Could ultrawide-bandwidth laser technologies open the ICF parameter space?
Collaborators


University of Rochester
Laboratory for Laser Energetics


Naval Research Laboratory

L. Divol and P. Michel

Lawrence Livermore National Laboratory
Improved stability and/or CBET mitigation is likely required to achieve 100 Gbar pressures on OMEGA

Solutions to expand the ICF design space by mitigating LPI must consider both CBET and two-plasmon–decay (TPD) instabilities.

*IFAR: in-flight aspect ratio*
A multiwavelength LPI platform was implemented on OMEGA for focused experiments to study both CBET and electron plasma wave physics.

The wavelength of the seed determines the instability that is driven: IAW ($\Delta \lambda \sim 1$ nm), EPW ($\Delta \lambda \sim 100$ nm).

The laser team developed a novel tunable system using the OMEGA EP OPA to achieve $\Delta \lambda_{UV} = 3$ nm.

Tunable OMEGA Port 9 (TOP9) was activated on 8 June 2018.

IAW: ion-acoustic wave
EPW: electron plasma wave
OPA: optical parametric amplifier
The CBET experiments will test the limitations of the CBET models that are implemented in our codes (LPSE, LILAC, DRACO, HYDRA).

Experiments will investigate the effects of beam smoothing (SSD, phase plates), transient effects on CBET, and the nonlinear plasma wave response.

SSD: smoothing by spectral dispersion
Extending the platform to six interaction beams will investigate the limitations of current multibeam CBET modeling.
Using a $2\omega$ (527-nm) seed beam will enable electron plasma wave studies very similar to the CBET (IAW) studies.

These experiments will test the linear response of electron plasma waves and the amplitude for hot-electron generation in both single-beam and multibeam configurations.
A three-color OMEGA is predicted to mitigate both CBET and hot-electron generation.

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**CBET mitigation**

- Laser absorption (%)
- \( \Delta \lambda / \lambda \) (%)
- \( \Delta \lambda \) (nm)

**Hot-electron mitigation**

- \( f_{\text{hot}} > 50 \text{ keV} \)
- \( \Delta \lambda / \lambda \) (%)
- \( \Delta \lambda \) (nm)

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Ultimately a broadband ICF driver could be the avenue to fusion

Stimulated rotational Raman scattering

Input laser

Output spectrum

Simulated output

Effects of bandwidth on CBET (LPSE simulations)

Effects of bandwidth on TPD (LPSE simulations)


A conceptual layout for a broadband OMEGA employs a modular approach that leverages the existing OMEGA infrared laser system.

Broadband DKDP OPA amplifiers

A collinear OPA could provide >10% bandwidth for a modern ICF driver.

SHG: second-harmonic generation
THG: third-harmonic generation

Replace current frequency-conversion crystals
LPI’s set the design space for all three approaches to ICF

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